EDUCATIONAL THEORY & PRACTICE FOR SKILL DEVELOPMENT IN THE GEOSCIENCES

by

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ABSTRACT

A movement from the traditional to the modern in geoscience education occurs through piecemeal application of educational theory to geology teaching. This dissertation developed and examined four traditional and innovative geosciences skills-based learning activities through qualitative, quantitative and mixed-methods methods:

A. Mineralogy laboratories were designed to improve learning gains (i.e., knowledge) and students' perceptions of mineralogy topics, primarily using group work. Groups of sizes 3 and 4 were most effective (compared with pairs, and groups of 5 and 6) in improving student collaboration.
B. An inquiry-style videogame was designed and tested in order to compare learning gains to that of a geological field trip. Though learning gains were slightly higher in the fieldtrip, some aspects of the videogame were more successful at increasing the depth and awareness of observation skills needed.
C. Field notebooks were analysed for uniqueness and completeness to quantify differences among participants' note-taking. We found that previous geologic experience, gender, and lecturer teaching styles all contributed to the students note taking abilities and perceptions of note-taking.
D. The design research of the Volcanic Hazards Simulation resulted in identification of critical pedagogical variables that encourage students' transferable skills: a) the pace of the simulation, b) the preparedness of the students, c) the role and team authenticity and d) communication best practices.

Meaningful changes to the curriculum of labs, field and experiential teaching methods resulted in the improvement of content knowledge, perceptions and skills of geoscience students. Collectively, these results suggest practical and theory-based solutions grounded in Constructivist paradigms to provide improved geoscience teaching at Universities.

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CO-AUTHORSHIP STATEMENT

This thesis includes three manuscripts which have been prepared for publications in scientific journals.

Chapter 2 has been published in the ***Journal of Geoscience Education*** (Dohaney, Brogt and Kennedy 2012). I am the first author and my co-authors are Dr. Erik Brogt and Dr. Ben Kennedy. I was responsible for all data collection, marking and creation of curricular materials. Dr. Kennedy and I shared the decision-making of which design elements to implement in the new curricula. He also collected initial feedback from students in the course. Dr. Brogt assisted me in the analysis of the pre- posttest data. I drafted all figures, preliminary results and wrote the majority of the manuscript. Dr. Brogt and Dr. Kennedy contributed to the editing of the manuscript. Permission has been granted by the editor of the Journal of Geoscience Education (see Appendix A1) and the co-authors of this work (see Appendix A3).

Chapter 3 has been submitted to the ***Journal of Geoscience Education*** (Dohaney, Brogt and Kennedy in review). I am the first author and my co-authors are Dr. Erik Brogt and Dr. Ben Kennedy. This study investigated the practices and perceptions of geosciences field note-taking. The experiment designed in this study was my work, including the instruments used and the methodology implemented. I carried out the analysis of the notebooks and interviews with some assistance from Dr. Brogt and Dr. Kennedy. I drafted the manuscript and created all illustrations and figures. Editing of the manuscript was assisted by Dr. Brogt and Dr. Kennedy. Permission has been granted by the co-authors (see Appendix A4).

Chapter 4 has been published in the ***Conference Proceedings of the New Zealand Geothermal Workshop, 2012*** (Dohaney, Kennedy, Brogt and Bradshaw 2012). I am the first author and my co-authors are Dr. Ben Kennedy, Dr. Erik Brogt and Hazel Bradshaw. This study investigated the use of a geosciences videogame. This videogame was co-designed and produced by Hazel Bradshaw. In our collaboration, I was the 'client' or 'Director' (i.e., provided the geosciences content, narrative and educational theories used in the design) and Hazel is the Producer (i.e., builds, designs and studies the videogame). Hazel's research on our design (i.e., interface, technology utilized) of the videogame will be presented in her dissertation in the coming years. The pre-post observations test discussed in this publication was created and the results were analyzed and interpreted solely by me. I drafted the manuscript and created all illustrations and figures. Editing of the manuscript was assisted by Dr. Brogt and Dr. Kennedy. Permission has been granted by the organizing committee of the Geothermal Workshop, who was responsible for editing and reviewing all manuscripts (see Appendix A2) and the co-authors of this work (see Appendix A5).

GLOSSARY OF EDUCATIONAL TERMS

Active Learning	Teaching and learning which requires students to do more during instruction than simply listening (i.e., Passive Learning).
Assessment	Methods of measuring and assessing the learning of knowledge, skills or values. Assessments can be broken into two categories: formative (i.e., qualitative, feedback-driven) and summative (usually multiple-choice, i.e., measurement-driven).
Authentic Learning	The teaching of skills and concepts that are grounded in the setting and context of actual practices in a discipline.
Autonomy	In educational settings, this term is referring to a person’s sense of ‘control’ and ‘independence’. Autonomy contributes to a feeling of confidence.
Collaborative Learning (i.e., Group Learning, Cooperative Learning)	Any learning activity which encourages interactions between peers and others. These activities rely on the members working together to achieve the learning outcomes.
Cognitive Load	A cognitive psychology term which refers to the strain that is put on one working memory resources during instruction. A person’s resources can be overloaded, under-loaded or appropriately challenged.
Constructivism	An educational theory which argues that knowledge is constructed by the learner when they encounter new information through experience. Social constructivism argues that learning is enhanced through experiences with others.
Curriculum	Curriculum (or curricula, singular) is a set of learning content and activities.
Design-based Research	A subdiscipline of educational research which studies learning activities in their natural settings and follows an iterative intervention/data analysis loop.
Educational Technology (i.e., e-Learning, Virtual Learning)	Any form of technology used to simulate or assist the learning process.
Efficacy	A feeling of confidence. Self-efficacy refers to the confidence in one’s self and one’s abilities to carry out a task.
Engagement	A person’s level of interest and attention to a specific learning activity. A student is considered ‘engaged’ if they are actively participating in the learning activity.
Experiential Learning	A learning theory which advocates students learning through and from experience.
Expert	An expert is a person with extensive knowledge and skills in a given discipline.

Field-based Learning	A teaching approach where the majority of learning occurs in the outdoors on field trips.
Graduate Attributes	Specific 'soft' skills and characteristics which are desirable in science graduates. For example: Transferable skills such as communication and time management skills or characteristics such as 'Independent' or 'Timely'.
Group Work (i.e., Group Learning, Collaborative Learning)	See Collaborative Learning (above); Compared to Individual or Solo Learning experiences.
Inquiry-based Learning	A teaching approach which allows the learner to experience a problem or scenario through discovery with differing levels of support. Field-based and problem-based learning styles are examples of this approach.
Labs-based Learning	A teaching approach which revolves around a spectrum of activities that occur in the laboratory. Many researchers refer to the 'hands-on' activities which are posed to students in this setting.
Learning gains	A comparable measure of learning. These values are calculated by comparing each individual participant's pre-test scores to post-test scores.
Learning goals (i.e., Learning "outcomes")	Specific statements which describe what the instructor would like the students to be able to achieve by taking part in the learning activity.
Misconception	A concept or perception which a student holds that is incorrect or derived from flawed understanding.
Motivation	In educational research, motivation refers to the psychological drive to participate and engage in any stage of learning.
Novice	A novice is a person with little knowledge and skills in a given discipline. Novices are often new to the discipline or practice.
Pedagogy	The way in which one or a collective teaches; teaching style or strategy.
Perception (i.e., attitudes)	In education, perceptions refer to values, attitudes and beliefs which students and instructors hold that can affect learning.
Problem-based Learning	A teaching approach which focuses on students learning through problem-solving experiences.
Role-play	A teaching approach in which the students and teachers take on roles in a specific scenario or setting.
Rote Learning	A teaching approach which encourages students to memorize concepts through repetition.
Rubric	A tool which is used in formative assessments. Rubrics include categories, with a spectrum of excellent to poor quality characteristics (communicated in statements), that the learning activity is designed to achieve.

Scaffolding	Supportive learning prompts which are used to guide the learning process. As the learner improves, the instructor can diminish support, until they can perform the learning task by themselves.
Scenario-based Learning	A teaching approach where the students are presented with a scenario (i.e., problem, setting and attitude) in which they might explore, solve a problem, or propose a solution.
Schema (schemata, plural)	Schema is a psychological concept which describes an idea or set of ideas in organized patterns or structures within the mind.
Simulation	In educational research, this refers to any activity which imitates real life process, systems, or behaviours.
Situated Learning	A teaching approach that takes place in the setting and context for which it is formally practiced.
Skills-based Learning	A teaching approach that focuses on students practicing and refining skills. These skills may be discipline-specific (e.g., geologic skills) or transferable skills.
Socratic Method	A method of discourse that occurs in a learning activity of which answers are not given to students immediately, or directly, but where the facilitator supports learning through continual inquiry and questioning.
Student-centred Learning (i.e., Learner-centred)	A learning context or setting in which the curriculum and pedagogy is framed around the needs of the learner, not the teacher.
Transferable Skills	Skills which are applied across the disciplines and can be transferred to many settings and scenarios. For example: communication skills and teamwork
Transfer	A psychological concept which describes the transfer of knowledge from the working memory (i.e., short term memory) to the long term memory.
Virtual Learning	A teaching approach which utilises educational technology to create simulations, problems, settings or supportive media which hosts or delivers the curricula to the student.

DEDICATION

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PREFACE

(Artwork by Jacqueline Dohaney)

You cannot teach a man anything; you can only help him find it within himself.

- Galileo

CHAPTER 1: TEACHING & LEARNING – THEORY & PRACTICES

Educational researchers study the perceptions and behaviour of students and teachers in the classroom, laboratory, virtual and real field environments. In each environment, there is a complex social setting containing multiple individuals; each with their own intentions and interpretations of the situation, who influence one another's knowledge, opinions, values and interact to produce shared experiences (Jarvela, Jarvenoja and Veermans 2008). The nature of the tasks confronted, the ways in which information is presented and the expectations for the learner's involvement all affect the learning process (Ericsson and Lehmann 1996; van Merriënboer, Kirschner and Kester 2003). Generally, educational research can incorporate theory from a range of disciplines including neurosciences, psychology, sociology, anthropology and philosophy (Bransford, Brown and Cocking 2004). Specifically, geoscience education is an interdisciplinary research area that examines and integrates educational theory in the context of earth sciences teaching and learning.

This thesis details the pedagogical variables which are critical for the effective design and delivery of geoscience curricula. The broad aim of my doctoral research was to use skills-based strategies within a Constructivist framework to target four different learning environments and apply theories of teaching and learning to develop more accessible, effective and engaging curricula with the intent to improve students' geoscience attributes and skills to proficient levels. I applied tailored methods to answer specific research questions related to these curricula and activities to provide new insights into educational theory and the nature of geoscience expertise. The learning environments that I investigate are 1. the laboratory, 2. the virtual environment, 3. the field and 4. situated learning role-play. I investigate the appropriateness of educational theories such as goals-based curricula design (e.g., Krajcik, Neill, Reiser and McNeill 2008), authentic learning environments (e.g., Herrington and Oliver 1995), cognitive load theory (e.g., Chandler and Sweller 1991) and novelty space theory (e.g., Orion and Hofstein 1994) to answer specific geoscience core skills, fieldwork methods and the use and assimilation of educational technology in the geosciences.

These theoretical concepts are discussed below. A glossary is provided at the beginning of the thesis for readers unfamiliar with educational jargon. This chapter reviews fundamental educational theories that underpin geoscience education research and student learning in the laboratory, virtual, field environments and during situated learning role-play scenarios (Section 1.1 and Section 1.2) and concludes with a detailed overview of the research goals and organisation of the thesis (Section 1.3).

1.1 COGNITION AND EDUCATIONAL THEORY

In order to develop educational practices in the laboratory, field, virtual and role-play environments, it is essential to first examine how people *learn*. Philosophers have long praised the importance and relevance of learning; both Greek (e.g., Socrates, Plato, Aristotle) and Chinese cultures (e.g., Mencius, Confucius) have put forward that to learn is to think critically and to question nature and one's self. More recently, John Dewey, Jean Piaget, Lev Vygotsky and David Kolb, among others, have all made significant contributions to the modern concepts of teaching and learning and the Constructivist paradigm, which is the foundation for this study; their findings and implications for this thesis will are discussed below.

Constructivists assume that knowledge is constructed (by the student) from previous knowledge, regardless of how a student is taught because it is believed that the mind has evolved to process outside stimuli, to make sense of them and to draw connections to prior knowledge (Cobb 1994). Constructivists perceive learning as a developmental process (Piaget 1954) in that learning is achieved through experience (sensory, mental and physical) and that 'knowing is interpreted through the context of doing' (Jonassen and Rohrer-Murphy 1999). They propose that students come into formal education with a range of prior knowledge, skills, beliefs and concepts that influence what they observe in a given environment and how they interpret it (see e.g., Bransford, Brown and Cocking 2004). Below, I introduce the works of these educational theorists in chronological order.

Dewey was an early contributor to the Constructivist school of thought and a pragmatist who believed that learning and theories about learning must be informed by experience. His educational works "The Reflex Arc Concept in Psychology" (1896), "The Child and the Curriculum" (1902) and "Experience and Education" (1938) suggested that effective education was a marriage of content and context where the student interacts with the content in pursuit of answering questions that are presented in the socio-cultural context (e.g., authentic learning approaches follow these principles and are described further in Chapter 5). His theories greatly influenced later learning styles such as inquiry-based (Schwab and Brandwein 1962) and problem-based learning (e.g., Schmidt 1983) which are prevalent in today's science (Bransford, Brown and Cocking 2004) and geoscience laboratory curricula (see Chapter 2).

Piaget advocated for understanding learning through stages of development of schema (Piaget 1954; the concept of schema (singular) was originally proposed by Bartlett (1932)); that ideas and concepts are conceived and stored as simple schemata (through simple experiences; plural), which can be replaced by or adapted into complex schemata (through complex experiences). Therefore, he posited that intellectual development is composed of collective, interconnected concepts developed through interactions and experience with the world (Driver et al. 1994). New schema thus comes into being by modifying old ones. In this way, intellectual development is seen as progressive adaptation of an individual's cognitive schemata to the physical environment. The schema theory is the root of several supportive learning theories such as scaffolding (Wood, Bruner and Ross 1976; Vygotsky 1978), social constructivism and collaborative learning (Michaelsen et al. 1982; Michaelsen, Bauman Knight and Fink 2004; Watkins 2004). The pedagogical concepts of scaffolding and group work will be examined in Chapters 2, 4 and 5 in more detail for their role in the development and interpretation of learning in the lab, field and during role play scenarios.

Vygotsky pioneered the concept of 'Zone of Proximal Development'(ZPD) (Vygotsky 1978; Doolittle 1995), which stemmed from the idea that individual students are at different stages of intellectual development. This is fundamental to the discipline-based, tiered education system –

where students learn different content in different ways at different levels. Vygotsky also theorized that learning is socially-constructed because experiences are embedded in a social environment where people, objects and culture all contribute to learning (Vygotsky 1978; Driver et al. 1994). Vygotsky suggested that effective learning should occur in socially-supported (by peers and instructors) learning experiences (i.e., 'social' constructivism) such as discussion and group learning and that education should move away from rote-learning and memorization. Learning that incorporates discussion with peers has been shown to increase student efficacies, motivation, collaborative and communication skills (Corden 2001; Reznitskaya, Anderson and Kuo 2007). The influence of these social learning environments and practices will be considered further with the findings presented from the laboratory, role-play and field studies of Chapters 2, 4 and 5.

Kolb utilized the Constructivist theories of Piaget and Vygotsky in his work 'Experiential Learning' (1984), which proposed that a student acquires new knowledge primarily through new experiences where ideas are not fixed but are formed and re-formed through these experiences. Experiential learning theory proposes a holistic and integrative approach to learning which combines *experience*, *perception*, *cognition* and *behaviour* (Kolb, 1984). For Kolb, learning occurs where previous ideas (or schemata) are tested and are in disagreement with previous knowledge; therefore learning experiences that are challenging and conflicting to the student's prior knowledge should elicit more effective learning. He suggested that learning results from interactions with the environment and the people in the environment, rather than previous models of "transmission- learning" (i.e., learning is achieved through the delivery and collection of facts and figures) (Kolb and Kolb 2005). Experiential learning theory is the basis for the situated, authentic and group learning theories that are addressed in Chapters 2, 4 and 5.

The theories discussed above which were proposed by Dewey, Piaget, Vygotsky and Kolb influenced many current innovative education practices. Instructors can foster students' learning in simple or complex activities through inquiry-based, scaffolded experiences (Wood, Bruner and Ross 1976). In higher education, authentic and situated learning approaches (Anderson, Reder and Simon 1996) provide socially-constructed complex tasks which are delivered in face-to-face or virtual settings (Lunce 2006) that challenge learners similarly experienced by professionals in the workplace. These authentic tasks represent the end-goal of Constructivist paradigms; to teach students skills in a natural setting of the lesson surrounded by peers. Brown, Collins and Duguid (1989) pioneered the use of situated learning approaches in classroom practice. These authors suggest that successful situated learning models contain elements of: apprenticeship and coaching, (i.e., first-hand, supportive tutoring between experts and novices), collaboration (i.e., working in pairs or groups to achieve outcomes), reflection (i.e., giving students opportunities to reflect or debrief on experiences), multiple practice (i.e., repetition of tasks) and articulation (i.e., opportunities to speak and write as professionals do). These practices were designed with the aim to immerse students into authentic practices through activity and social interaction (Brown, Collins and Duguid 1989).

Vygotsky's construct of ZPD and Csikszenthmihalyi's construct of "flow" (i.e., self-defined, optimally challenging experiences; Csikszentmihalyi, Abuhamdeh and Nakamura 2005) argue that individualized experiences with authentic 'real-life' learning tasks are highly motivating, yet often strain the cognitive resources of novice learners (van Merriënboer and Sweller, 2005). Cognitive load theory is the current understanding of how working memory 'resources' are managed during learning and problem solving tasks (Sweller 1988). Experts *chunk* simple concepts together in meaningful structures (i.e., schemata) and can therefore handle more complex working problems (van Merriënboer and Sweller 2005). Novices on the other hand, do not have these previously built schemata and struggle with handling many new concepts simultaneously (van Merriënboer and Sweller 2005). Aspects of this work aimed to replicate ‘real’ or ‘near-real’ life scenarios with authentic problems and settings (see Chapter 5) through well-designed interactive multimedia environment that provide opportunities for apprenticeship, inquiry and supportive (i.e., scaffolded) learning (Young 1993; Lunce 2006) (See Chapter 4). All of the above learning theories are concerned with the manner in which the learning of knowledge and skills is acquired.

Students will not acquire skills if they are not motivated and therefore the consideration of theories of motivation is important to educational research and curriculum design. Seminal work by Maslow (1943) and later Dweck and Leggett (1988), Eccles and Wigfield (2002), Eccles (2005) and Ryan and Deci (2000) proposed that an individual’s motivation to engage in learning is self-defined and is based on several important factors: feelings of recognition, responsibility, personal growth, autonomy and overcoming challenges (Beard 1972). Constructivist learning paradigms embrace authentic, situated and socially-constructed learning activities. These types of activities can be inherently more engaging and motivating to students because they demonstrate their context and use, present optimal, customized challenges and allow students to engage in a socially interactive experience grounded in an authentic setting.

The following section examines geoscience educational theory and practice in the context of previously discussed theories and practices.

1.2 EDUCATIONAL THEORY AND PRACTICE IN THE GEOSCIENCES

The study of the geosciences requires a unique set of skills (King 2008). Understanding the Earth system is as crucial to future citizens as other traditional sciences (e.g., physics, chemistry and biology) (Orion 2007) as climate change, overpopulation, natural hazards and unsustainable resource exploitation all pose significant threats to the inhabitants of the Earth. Therefore, understanding how the geosciences are taught and learned is fundamental to our success as a society. Traditionally, the geosciences have been taught with an emphasis on factual knowledge in "cookbook" style teaching rather than inquiry-based teaching approaches (Ireton, Mogk and Manduca 1997). Authentic inquiry and exploration teaching methods in geoscience generally occurs as part of field mapping courses (Gonzales and Semken 2006; Elkins and Elkins 2007), which are relatively infrequent (compared with traditional methods) in the curriculum due to the intensive time, resource and financial commitment required.

The study of the Earth requires learning a versatile set of skills and conceptual knowledge of chemistry, physics and biology. Students are traditionally presented these concepts in the lecture hall, laboratory and on field trips. Significant work has already been done in the lecture learning in the sciences (e.g., McKeachie 1980; Prothero 2000; Deslauriers, Schelew and Wieman 2011; Kennedy et al. 2013), therefore in this thesis, I focus on the laboratory and field environments and additionally investigate novel learning environments that I predict will become increasingly relevant to 21st century learning; the virtual learning environment and that of role-play training simulations. Generally, laboratory and field work learning are opportunities for students to get hands-on experience with the rocks, minerals, fossils and larger-scale features which are fundamental to Earth's processes. In the geosciences, like other field sciences, practical skills are acquired in a holistic way (Emerson 1995) or through an 'apprenticeship' or internship, where one-on-one feedback is provided later in their career. Therefore, the virtual world and role play scenarios (See Chapters 3 and 5) represent complementary supplements to resource-intensive apprenticeships that are not available to all students. Additionally, these simulated learning experiences make ‘field work’ available to students with financial hardships or physical disabilities.

Skills are commonly understood to be acquired best through participation and practice (i.e., active learning techniques), hence authentic activities are needed through which specific skills can be learned and practiced (Lonergan and Andresen 1988). The use of learning goals has been shown to be useful to both student and instructor (Simon and Taylor, 2009) as it makes the curriculum design centred on the student and what the student “should be able to do”. Bloom’s taxonomy of the cognitive domain categorizes what students are being asked “to do” into different levels of learning (Bloom et al. 1956; Lord and Baviskar 2007) and was the preferred guide used in this thesis for aligning the curriculum to learning outcomes. Curricula can focus on lower-levels of recall-style skills typical of novices or can focus on “applied” complex skills (higher-level; typical of experts). The curriculum design involved in this thesis relied upon creating goals that are necessary for the students’ future profession. Figure 1.1 illustrates the Bloom’s learning goal levels, common geoscience “doing” verbs and examples of the type of learning goals used within geoscience curricula in this thesis.

Figure 1.1: Bloom's taxonomy learning stages (Bloom et al. 1956; Isaacs 1996; Lord and Baviskar 2007) illustrating the common learning goal verbs that are addressed in the geosciences. All levels of Bloom's cognitive learning stages were addressed, and often curricula required scaffolds from low-level goals to achieve high-level goals.

	Bloom's Level	Learning Goal Verbs	Thesis examples	
LOW LEVEL	1. Knowledge	Define, Label, List	**Define** the term 'diagostic property' (Chp 2) **Label** the features on your field sketch. (Chapter 4)	NOVICES
	2. Comprehension	Describe, Summarize, Locate, Identify	**Describe** the mineral specimen (Chapter 2) **Locate** yourself on a map (Chapter 3 and 4) **Summarize** ash impacts to agriculture (Chp 5)	
	3. Application	Observe, Illustrate, Demonstrate, Collect	**Observe** and **record** qualitative data from a geothermal hot spring (Chapter 3 and 4) **Illustrate** the distribution of ash from a Vulcanian eruption on a map (Chp 5)	
	4. Analysis	Explain, Differentiate, Compare/Contrast	**Compare** the physical properties of minerals with SiO_4 versus CO_3 anions (Chp 2) **Differentiate** between small and large scale eruptions using visual data (Chapter 5)	
	5. Synthesis	Synthesize, Plan, Compose, Propose	**Synthesize** multiple datasets to produce a working model of volcanic activity (Chapter 5) **Compose** a media release following an Alert Level change (Chapter 5)	
HIGH LEVEL	6. Evaluation	Weigh, Recommend, Evaluate, Verify	**Weigh** the economic and social impacts of a large scale eruption (Chapter 5) **Make recommendations** to the public about ways to stay safe following an eruption (Chp 5)	EXPERTS

There are four areas of geoscience skills that form the focus of this thesis: a) laboratory skills in introductory labs (Chapter 2), b) observations and note-taking skills in the field (Chapter 4), c) field skills in a virtual environment (Chapter 3) and d) transferable skills (i.e., communication and teamwork) in a role-play simulation (Chapter 5).

The laboratory setting is deemed essential for learning the necessary conceptual skills of mineral and rock identification knowledge and basic geological mapping principles (Plymate, Evans and Mantei 2005). It is an environment where students can scaffold practical skills and knowledge with classroom theory and knowledge while interacting with each other to build schemata. The laboratory can also be an authentic, potential work environment for geoscience graduates.

Field trips offer many valuable opportunities to learn theoretical concepts, develop specific observation and recording skills through note-taking and enhance understanding (e.g., Kern and Carpenter 1986; Her Majesty's Inspectors 1993; Elkins and Elkins 2007). A diverse range of field specific skills are fundamental to the geoscience graduate, yet many skills such as note-taking are rarely explicitly taught (Van Meter, Yokoi and Pressley 1994). Additionally, field trip curricula differ institutionally as geoscience students are given fewer, longer (weeks to a month) field trips; frequent, shorter (day-long to several days) field trips (Maskall and Stokes 2009) and the rare institution offers frequent, longer field trips to practice these important skills.

This is predominantly due to reduced departmental funding and increased student numbers (Gold and Haigh 1992; Bradbeer and Livingstone 1996). However, educational research has shown that the field environment presents significant and engaging learning challenges even to expert geologists, as it is composed of 'novel' cognitive, psychological, social and geographic variables (Orion and Hofstein 1994), which makes instruction and acquisition of effective skill sets more difficult.

In recent years, virtual environments have emerged as a popular means of teaching geology and other science disciplines. These include: virtual laboratories (Clary and Wandersee 2010), virtual field trips (Browne 2005) and two-dimensional videogames (Schwert, Slator and Saini-Eidukat 1999).Videogames can enable learners to see and interact with natural geologic phenomena that may be difficult or expensive to access in person. Interactive technology can also present learners with explicit challenges and feedback. This technology provides instant, individualized feedback customized to the needs of each student (Honey and Hilton 2011). This level of one-on-one feedback is rarely replicated in other formats.

The last area of skills acquisition research is concerned with a natural hazards role-play simulation. Simulation-based learning in the geoscience allows students to explore scenarios and solve problems (Van Ments 1999) that practicing geologists face. The goals of most situated learning activities are to teach critical thinking, decision-making, teamwork and other transferable skills in the context of the discipline. Generally, the geoscience community has recognized the deficit of quality teamwork and communication skills in its graduates (Ireton, Mogk and Manduca 1997; Dannels 2002; Heath 2000; Heath 2003) and the importance of communicating complex geological phenomena to the public (Newhall and Hoblitt 2002; Haynes, Barclay and Pidgeon 2008). “Earth system science instruction should not only incorporate genuine inquiry and hands on experience but also teach communication skills, teamwork, critical thinking and lifelong learning skills” (Ireton, Mogk and Manduca 1997).

The simulation considered in this study incorporates group learning and role-play pedagogies. These pedagogies are grounded in Constructivist learning theories that encourage dynamic, student-centered learning and are often found to improve transfer of practical and theoretical skills (e.g., Roth and Roychoudhury 1993; Lunce 2006).

1.3 SPECIFIC RESEARCH QUESTIONS AND ORGANISATION OF THE THESIS

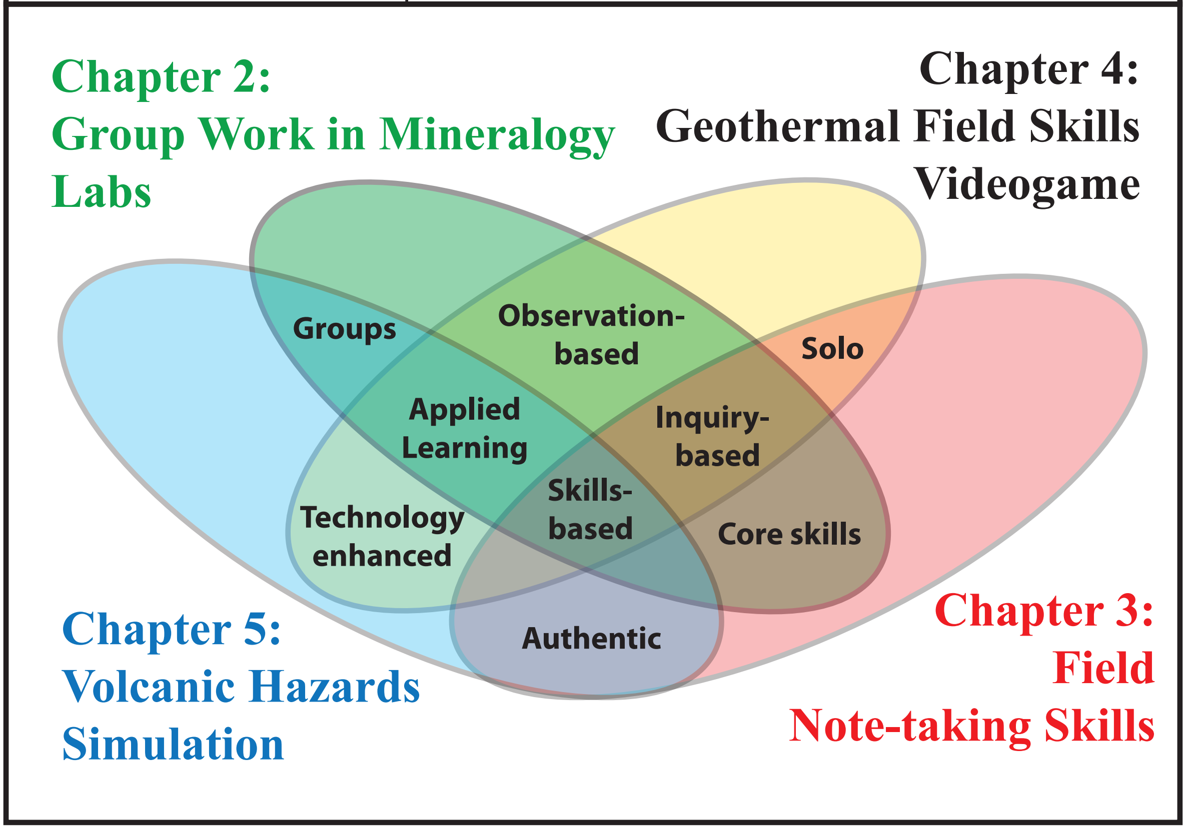
To illustrate how the thesis is organized, I present the Constructivist pedagogy and educational theory relevant to each chapter and associated learning environment. Figure 1.2A shows the theory-based learning approaches that were utilised in the thesis, while Figure 1.2B illustrates how specific teaching and learning strategies and theory overlap significantly between the studies. In each chapter I used evidence-based approaches to examine and critically assess each research question. I then used the Constructivist approach and application of education theory to discuss the specific research questions (listed below) and recommend best practices for geological educators.

Chapter	***Research Questions***
Chapter 2: Lab curricula and group work	How do applied and customized projects support engagement in the lab learning experience? What elements of group work promote learning in this setting?
Chapter 3: Games-based learning of field skills	How do field-based videogames compare to field learning activities? (equivalent/less than learning gains to a field activity) What are the positive and negative aspects of learning field skills with videogames?
Chapter 4: Best practices and classification of note-taking in the field	What factors affect a learner's abilities to take notes in a field environment?
Chapter 5: Complex, authentic volcanic crisis simulation	What elements of design affect the individual and collective (team) behaviors and perceptions of learning in a complex simulation?

Constructivist pedagogy within the curricula of each study were matched to the setting and consistently overlapped. This work aimed to understand and improve geoscience student learning in these diverse settings. Evidence-based approaches were used to examine the research questions posed. Lastly, the conference proceedings and contributions that have been made during my doctoral research related to these works are included in Appendix E.

Figure 1.2: A. (top) Theoretical concepts which are covered in each Chapter of the thesis. The larger check-marks refer to more application of these concepts. B. (bottom) A Venn diagram illustrating the overlapping learning strategies (i.e., pedagogy) within the thesis. Chapters 2-5 are shown below, with fields labelled with learning strategies which are shared between the sections.

	Chapter 2	Chapter 3	Chapter 4	Chapter 5
Goals-based Curriculum Design	✓	✓	✓	✓
Authentic Learning Environment		✓	✓	✓
Cognitive Load Theory	✓	✓	✓	✓
Novelty Space		✓	✓	



CHAPTER 2: SUCCESSFUL CURRICULUM DEVELOPMENT AND EVALUATION OF GROUP WORK IN AN INTRODUCTORY MINERALOGY LABORATORY

PREFACE

I hear and I forget;

I see and I remember;

I do and I understand

- *Confucius*

The educational theories utilised in this study hinges on skills-based techniques developed from the ***Constructivist paradigm*** discussed in Chapter 1. Chapter 2 discusses the development and testing of a new introductory mineralogy curriculum which was designed at the University of British Columbia (UBC) in Vancouver Canada. All of the curricular design and data collection occurred at UBC and analysis and synthesis was carried out at the University of Canterbury, during the first year of my doctoral research.

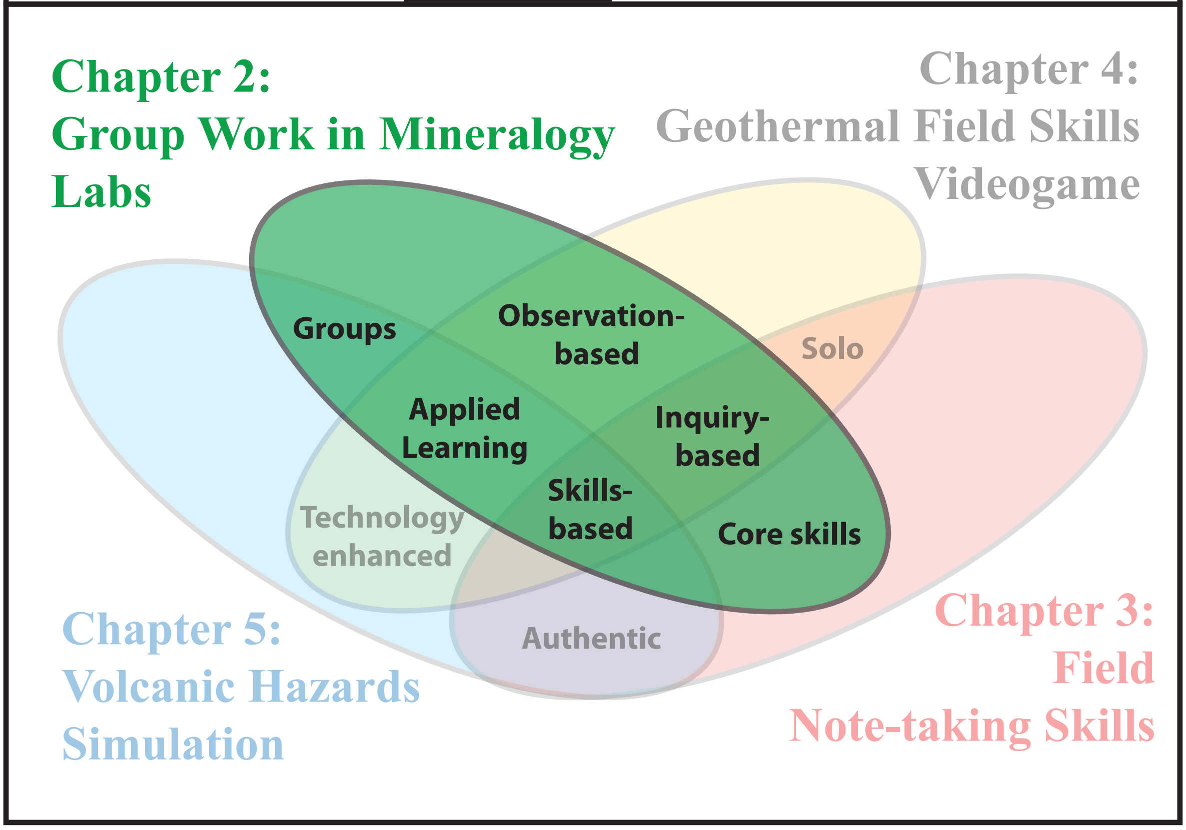
We highlight herein how the elements of this chapter fit into the theoretical constructs and learning strategies that underlie the thesis (See Figure 2.1). This chapter presents a ***goals-based curriculum*** redesign of laboratory assignments. The new assignments attempt to increase the Bloom's learning levels (Figure 1.1) of previous laboratory assignments by ***scaffolding*** (i.e., experiences which continually build upon previous knowledge) skills and knowledge whilst maintaining a reasonable ***cognitive load*** (Figure 1.2).

The classroom and the laboratory are no longer places of teacher-centred, ***solo*** (i.e., ***individual***) learning experiences where tutors apprentice students one-on-one, but instead consist of large classes, with a student-centred approach usually incorporating applied and ***group learning*** techniques. These new strategies of teaching and learning have been used to teach students ***transferable skills*** such as teamwork, time management and communication as well as the ***practical observational skill*** sets of a geoscientist. The students use ***inquiry*** (i.e., discover the content and skills) to develop knowledge through the activities which are ***scaffolded.***

The results of this study illustrate that group learning techniques can be used to teach students more effectively than by traditional means. Lecturers from all laboratory-based sciences can incorporate aspects of this approach into their teaching for more interactive, peer-supported, feedback-rich classrooms.

Figure 2.1: Theoretical concepts (top) and learning strategies (bottom) which are discussed in Chapter 2.

	Chapter 2	Chapter 3	Chapter 4	Chapter 5
Goals-based Curriculum Design	✓	✓	✓	✓
Authentic Learning Environment		✓	✓	✓
Cognitive Load Theory	✓	✓	✓	✓
Novelty Space		✓	✓	



2.1 INTRODUCTION

Introductory mineralogy is typically a foundational course in a geoscience degree program and a prerequisite for other core topics (e.g., petrology, field geology). All Earth scientists learn about minerals and their properties, as they are the fundamental building blocks of the Earth (Nickel 1995). There is ongoing discussion in the geological community on the curriculum and the way in which this subject is taught Constantopoulos 1994; Brady, Mogk and Perkins 1997; Dutrow 2004; Reinhardt 2004; Swope and Giere 2004; Perkins 2005; Boyle 2007; Mogk 2007; Wirth 2007). This discussion is represented by a continuum of mineralogy courses that exist between “traditional” crystallographic theory-based and practical identification-based mineralogy needed for petrology subjects (Dutrow 2004).

Mineralogy courses often have a laboratory module that is used to teach both the theory and the practical skills needed for mineral identification. The American National Research Council defines laboratories as: “[places] where students interact directly with the material (or with data), using tools, data collection techniques, models and theories of science”(Singer et al. 2005). Faculty and alumni of the geosciences consider laboratories (or an equivalent format) essential for teaching the necessary basics of mineralogy and petrology (Plymate, Evans and Mantei 2005). The 2.5 hour, weekly laboratory sessions discussed in this paper are a part of a new mineralogy curriculum at UBC which has been designed to integrate both theory and mineral identification. Labs can offer an excellent stage for learner-centered environments that require active and collaborative learning. In this paper, we discuss the use of group work as an effective part of the laboratory format in the introductory mineralogy course at UBC. The introductory mineralogy laboratories are introduced below.

2.2 MINERALOGY AT UBC

At UBC, mineralogy focuses primarily on crystallography and hand sample identification techniques. The mineralogy course size typically ranges from 100-110 students per semester, with 5 different laboratory sessions, of 12-30 students, each taught by one graduate teaching assistant (TA).

Like other institutions with large class sizes and limited budgets, UBC had low TA-to-student ratios and therefore provided only limited opportunities for personal and meaningful student-instructor interactions (c.f., Goodman, Koster and Redinius 2005). Students worked individually through the weekly laboratory activities from a crystallography text by Klein (2007) and many students left before completing the activities, as the laboratory work was not assessed on a weekly basis.

In early 2008, student feedback (n=44) was collected regarding the positive and negative aspects of the introductory mineralogy course. Feedback was collected via informal student surveys, emails and a small focus group. Table 2.1 lists the range of 'likes' (Table 2.1A) and 'dislikes' (Table 2.1B) from their responses, relevant to the laboratories. The most common 'like' was the mineral identification aspect. The most common 'dislikes' were that the laboratories were too long, the laboratory text was 'bad' and that there was too much memorization of content. The primary pitfalls of the laboratories include lack of organization, running overtime, a laboratory text that did not match the context of the course and too much memorization.

Table 2.1: Baseline Student Feedback

A. What aspects of the lab did you most like? (open-ended)	**Responses**
Mineral identification was useful	9*
Hands-on aspects of lab	1
The TAs were really helpful	4
The lab was better than lecture for learning about minerals	4
B. What parts of the lab did you least like? (open-ended)	**Responses**
Not enough practice with physical properties	3
Theory and ID were not linked	3
Too much memorization	9
Bad lab text	10
Bad samples on exam	7
The room was uncomfortable	3
Labs were too long	13
Too much crystallography	1
No projects	3
Weekly labs weren't marked	2
Concepts were irrelevant	3

* number of responses; some students provided more than one response

As a result of negative student feedback, the introductory mineralogy course was restructured as part of the Carl Wieman Science Education Initiative (CWSEI) (Carl Wieman Science Education Initiative 2009). CWSEI is a multi-institutional initiative which aims to improve the design, delivery and assessment of teaching and learning of tertiary science courses. The primary objective in the introductory mineralogy course was to encourage student engagement in the laboratory via curriculum alignment and grounded pedagogy. Specific re-design objectives were set out to address the main issues with the previous laboratory curriculum identified through the student feedback using learning techniques grounded in science education best practices (see Section 3 for more details).

The re-design objectives included:

1. Learning goal-based restructuring and reduction of the laboratory content volume to encourage scaffolding of topics and to reduce the cognitive load (i.e., the burden placed on student's working memory during instruction; c.f., Chandler and Sweller 1991) of the weekly laboratories.

2. Introducing laboratory activities with applied topics (e.g., ore mineral usage and global distributions or advanced petrology topics such as mantle petrology) and customized individual projects.

3. Implementing evaluation and assessments that provide frequent, meaningful feedback.

4. Promoting group work to encourage peer-supported learning and engagement and to satisfy logistical purposes such as TA weekly budgets.

In the next section, we discuss the rationale for these changes, the implementation of the new curriculum and use of group work in more detail.

2.3 METHODS: RESTRUCTURING UBC'S INTRODUCTORY MINERALOGY LAB

Changes made to UBC's introductory mineralogy laboratories took place over two years and in two stages. Stage 1 took place from January to August of 2008. It focused on the development of learning goals, pedagogy and assessments. Stage 2 took place just prior to the 2009 fall semester and consisted of fine-tuning the changes from Stage 1 based on student feedback from 2008. Blanket ethics approval was granted as part of the CWSEI initiative. Data were collected during the fall semesters of 2008 and 2009 (Table 2.2)

Table 2.2: Description of Data Collection

Date	Description
Fall, 2007	Informal feedback survey of one laboratory section *(Dohaney)* (n=18)
January-August 2008	Student attitude and feedback collected via emails (*Kennedy*) (n=21)
Stage 1 Fall, 2008	Small focus group in order to assess laboratory design (Labs 1& 2) (n=5) Pre-test (individual and group) (n=99) Midterm feedback survey (n=33) End of term feedback survey (n=56) Post-test (group) (n=108) All laboratory grades (i.e., mineral tests and final laboratory exam scores; n=112)
Stage 2 Fall, 2009	Pre-test (individual and group) (n=100) Midterm feedback survey (n=49) Post-test (individual and group) (n=99) All laboratory grades (n=103)

2.3.1 Stage 1: Original Redesign 2008

2.3.1.1 Learning Goal-based Restructuring and Reduction of the Cognitive Load

Learning is aided by proper organization through clearly communicated objectives using learning goals (Lord and Baviskar 2007; Krajcik et al. 2008; Simon and Taylor 2009) . Learning goals are especially important in courses with laboratory components. Course-level learning goals were developed (Table 2.3A) and placed into a linear structure where teaching of the non-silicate minerals occurred first, followed by silicate minerals. Topic level goals were often grouped into specific, repeatable, categories (See Table 2.3B) allowing us to easily link the laboratory assignments with the topics discussed in the lecture. Integrating laboratory experiences with lecture experiences helps students develop a mastery of the knowledge (Singer et al. 2005) through repetition and inquiry.

Learning goals also help students and instructors to identify what the important topics are. This gives us the ability to eliminate the extraneous activities that could be perceived as 'busy-work' by students, thus, reducing the cognitive load. The 'less is more' attitude can be useful in curriculum design and help instructors reduce the amount of content while introducing the relevant concepts in a meaningful way (Dempster 1993). One of the major criticisms of the previous design was that the laboratories were too long and the material required too much memorization (Table 2.1B). Reducing the amount of material that students are responsible for is a first step in reducing cognitive load. In consultation with faculty teaching into the upper division courses, the number of required minerals that students were responsible for identifying was reduced from 75 to the most common 55 minerals.

Table 2.3: Introductory Mineralogy Learning Goals

A. Course-level Learning Goals: By the end of this course, students should be able to…
1. Use atomic structure and crystallography to identify and explain the properties and groupings of common minerals.
2. Explain correlations between relevant chemical concepts (e.g., substitution and solid solution) and the parts of the mineral formulas that control the properties and groupings of minerals.
3. Describe and explain the processes and environments that lead to common associations of minerals in rocks.
4. Observe, describe and measure physical properties of mineral hand specimens in order to identify minerals and place them into groups.
5. Develop interpersonal and practical skills, which are useful for future careers such as working in groups to make decisions and preparing individual laboratory term projects.
6. Apply mineralogy concepts and skills learned in lecture and laboratory to geological, materials science, environmental and economic topics.
7. Appreciate the rarity, beauty and usefulness of Earth's minerals.
B. Topic-level goal categories. These were used to link the topics in lectures to the laboratory activities. Each week, these topics were covered:
1. Basics of Mineral Chemistry and Physics 2. Mineral Identification Techniques and the Science behind them 3. Applied topics: Guest lectures, Upper-year topics, Economic Mineralogy etc.

As our focus had changed, we wrote a new laboratory manual text that reflected the new learning goals. These new laboratories are shorter than those found in traditional crystallography texts and are designed to fit the 2.5 hour time slot. The activities are focused on inquiry-style activities where mineral identification techniques and observation skills are used to measure physical properties. By moving away from repetitive, 'recipe-like' procedures, we hoped to encourage understanding rather than memorization. In the previous laboratory format, students were asked to complete 30-40 problem-sets of crystallography theory and then proceed to cataloguing the diagnostic properties of 10-15 minerals. In the new format, students work through 4 laboratory activities that include 3-5 questions each and use the minerals to help answer these questions.

These new activities were designed to inspire deeper learning through a tactile approach to the scientific method. We aimed to reach a higher level of engagement by using comparative and observation skill-based learning goals such as **application** (e.g., use, demonstrate, examine, illustrate), **analysis** (e.g., distinguish, compare, differentiate) and **evaluation** (e.g., evaluate, verify) (Bloom et al. 1956; Isaacs 1996; Lord and Baviskar 2007). An example of one of these laboratory activities is to use the streaks of 10-15 sulphide and oxide minerals to differentiate them from one another. Outside of laboratory time, students are required to look-up mineral properties (e.g., mineral streaks) in a reference text or mineralogical websites to confirm their observations. Although the laboratory activities are to be completed individually, students are encouraged from the very beginning of the semester to work collaboratively and discuss the laboratory activities as a **group**.

2.3.1.2 Focus Group

We field-tested the new laboratory goals and organization with a small focus group (n=5) of students who had taken the course in the previous year. The focus group took place in mid-2008 when the laboratory manual was under construction, prior to the 2008 fall semester. The purpose was to obtain student feedback and assess their performance (pre- and post-tests) on two new laboratories (Lab 1 and 2). Duration of the laboratories was timed and shown to be between 50-90 minutes, well within the scheduled laboratory time. Students were broken into two groups and were tested as a group, before and after working through the laboratory material. They performed very well on the pre-test (average individual score of 74.1%) which is expected as they would have been introduced to some of the content in the semester before. Post-test group scores were higher than individual scores by 15-20% (Group 1; Lab 1: 85% and Group 2; Lab 2: 97%).

However, responses and performance are not representative of students who would be encountering the mineralogy content for the first time.

The students indicated that the new goals provided motivation and were useful and clear. Also the students thought that collaborative (in this case, paired) learning was useful and helpful for learning. One student stated, “I like [group learning], it’s like we solved it from different perspectives”.

2.3.1.3 Use of Applied Topics and Customized Student Projects

It is difficult for students to be motivated to do exercises if there is not any context for *why* they are learning (e.g., Bransford, Brown and Cocking 2000; p. 60). Student feedback from 2007 also reflected the need for context, as indicated by a representative student comment: “I really think the focus of the laboratories should be in the minerals, as we are more likely to use this info in the field”. Real-world applications can be the most direct method of demonstrating the context and purpose of conceptual learning. We tried to accomplish this by using applied topics and two individual and customized student projects. In the new laboratory manual, each laboratory has one (or more) activities that require students to apply basic concepts to a problem or applied topics (e.g., diamond exploration). The most relevant applied topics incorporated petrology concepts, such as mineral assemblage associations; crystal formation and growth conditions; and rock specimen modal mineralogy. These topics allow an introduction to the basic hand sample petrology skills that are needed for later courses in their degree program.

We also created two individual assignments: the MinBook assignment and the Poster Session. These projects served a motivational purpose, by allowing students to explore their individual creativity and to develop autonomy and resourcefulness. Individual projects require students to organize the material in a way that makes sense to them, helping to create meaningful cognitive frameworks for the information and allows them to retrieve it more effectively (Edelson 2001).

The MinBook assignment required students to look-up, test, verify and catalogue the properties and characteristics for each of the 55 required minerals. The project was used as a study-aid and ideally students should have been contributing to it weekly as they encountered new minerals. The objective of this was to produce personalized reference documents that students could use in following years of study. This encouraged students to focus on observing mineral properties and to catalogue these in their MinBook rather than only memorizing mineral characteristics. A major part of their MinBook was for students to create a reference system that allowed them to use the properties of the minerals to eliminate each grouping of minerals systematically during identification and to organize their book in a personally meaningful ways.

The Poster Session was a short oral presentation of a poster that each student created about a mineral of their choice. The minerals selected were not on the required mineral list. In both projects, students were asked to use external laboratory resources such as websites, textbooks and journals. Research shows that students will learn more effectively when concepts are reinforced outside of the laboratory or lecture environment (Singer et al. 2005). Students and teaching assistants were given rubrics so that expectations and marking were clear.

2.3.1.4 Evaluation and Assessments

Assessment is an integral part of feedback and can be the primary source of motivation for students. Most students value ample opportunities to articulate their ideas on their own and value any personal feedback they receive (Singer et al. 2005). Prior to curriculum development, the introductory mineralogy course at UBC had several assessments that were performed in the laboratory, including mineral identification tests and a laboratory exam. The worth of the laboratory portion of the course did not change from previous years and remains at 40% total (which includes mineral tests, student projects and a final laboratory exam).

The mineral tests given in 2007 (2 tests per term, each worth 5% of the total laboratory grade) the students were given 25-30 minerals (one at a time) and had to use their mineral identification techniques to identify which mineral was presented to them. Students were marked on correct identification (1 mark) and the correctly spelled mineral formula (1 mark). This scheme encouraged rote memorization.

The revised test emphasized observations and correct use of mineral identification skills. The marking scheme was changed to award for correct identification (1 mark) and 2 marks for 2 diagnostic properties that led to this identification. While the test remained closed-book, the shift in marking was to discourage students from relying on memorization and to encourage identification techniques and recognizing diagnostic properties of minerals. Lab activities in the new laboratory manual were also primarily focused on the chemistry of minerals (for example cation substitution or chemical-based mineral groupings) replacing the need for memorization of mineral formulae.

The previous introductory mineralogy laboratory included a laboratory exam for which the content was centred on crystallography. No hand samples were used in this format. In an effort to move away from a crystallography theory-based format and align with the new learning goals, the new laboratory exam (worth 15% of the total course grade) was pre-dominantly practical skill-based. We gave students several hand samples with minerals that display characteristic properties (such as crystal habit and form) and rock specimens in order for students to deduce mineral associations and environments.

In the previous format, students were not graded weekly and this led to a lack of motivation for students to attend laboratories and to complete them. We designed ‘group quizzes’ (7 quizzes, worth 1% each) to be completed at the end of each laboratory. Group learning had not been emphasized and rarely used in the previous format of the class. A description of why we chose to use group work and group assessment is in the following section.

2.3.1.5 Justification and Use of Group Work and Group Assessment

Unstructured group work and group assessment was introduced in the laboratories primarily for logistical reasons. Teaching of laboratories in North America is often done by graduate student teaching assistants (TAs), depending on the size of the department, student population and resources available. On the first day of lab, students were asked to form groups of their choosing, and were encouraged to select group members where they were seated even if they did not know the student next to them. In order to accommodate large laboratory sizes and insufficient TA marking hours, we encouraged group work during laboratory time followed by a short, structured, group quiz. Students were encouraged to take as much time to complete the quizzes as was needed. The quizzes could be marked weekly and would provide meaningful, feedback to be given to students the following week. With a class population of approximately 100 students, group quiz marking (rather than using individual quizzes) could reduce the weekly marking budget by up to 50-75%. Also, in-laboratory group work allows for more constructive and focused use of the teaching assistant’s time in laboratory in order to provide more meaningful feedback to students.

Fortunately, the logistical reasons for group work have a useful pedagogical by-product. Group work was used here primarily to encourage peer discussion during the weekly quizzes and laboratory work and to increase student engagement. Many studies suggest that there are advantages to group learning, specifically fostering collaborative discussion (Pray Muir and Tracy 1999; Barron 2010) and peer-learning (e.g., Smith et al. 2009). Group (or collaborative) testing also has many advantages such as promoting critical thinking of complex situations and teamwork (Lusk and Conklin 2003; Russo and Warren 2009; Wiggs 2011) . This new design created a weekly opportunity for feedback from the TAs, within the format of large laboratory courses. This allowed students to make mistakes and discuss their mistakes with minimal marking penalties while also allowing the TA sufficient time to pay attention to the learning needs of the entire class.

Group work and group testing can be useful for all students (Eaton 2009), but specifically low-achievers who are not as prepared for higher-level thinking and reasoning (Giuliodori, Lujan and DiCarlo 2008; Macpherson, Lee and Steeples 2011). Mineralogy lies at the beginning of most degree programmes where staff members have to teach students at widely differing stages of intellectual “readiness”. Socially, students can relate to one another, fostering good interpersonal interactions (Kapitanoff 2009), positive group experiences can lead to increased motivation to learn (Cortright et al. 2003; Slusser and Erickson 2006) and to attend class (Michaelsen et al. 1982). One of the course-level goals is focused on development of communication and other interpersonal skills (Table 2.3, Goal #5), so the use of group work can be instrumental in developing these. There can also be negative impacts of group work: the typical psychological factors when peers interact include overly extroverted ‘take-over’ personalities (Barron 2010) and ‘free-ride’(i.e., social loafing (Karau et al. 1993)), shy, or disenfranchised students who blend into the background because it is easier (and less risky) to receive the marking benefits without participating. Participation of students can be increased if the task is considered important (increased high marking value; such as exams (Cortright et al. 2003)), communication is valued and productive among members and if each member's input is respected by all members (Karau et al. 1993). But because task value is individually defined (Ryan and Deci 2000; Eccles 2005), some students may feel that group marking is an unfair method of assessment and this needs to be considered.

2.3.2 Stage 2: Fall term of 2009

As a result of student surveys and discussions with the TAs, several small changes were made to the 2009 curriculum based on feedback from 2008. Results are discussed in Section 4.

2.3.3 Instruments

In order to assess the effects of the curriculum on student learning, we created a short-answer, criterion-based test that students completed (individually and then together, as a group) at the beginning and end of the semester (the 'pre-post test'; Refer to Table 2.2 for the sequence of test-taking). Questions were taken from the weekly group quizzes, each one matching one of the learning goals and content covered in each laboratory. Our objective was to select open-ended questions that could elicit a range of misconceptions. The pre-post test is shown in Table 2.4. The instrument represents the first stage of development towards a validated mineralogy concept inventory, in development at UBC. We also performed standard, anonymous, voluntary, mid- and end-of-term surveys to assess students' attitudes. Student feedback surveys were anonymous and collected through e-learning tools (Vista or Web-CT). Many questions utilized a Likert scale. Questions and results are shown in Section 2.4.

Table 2.4: Pre-post Test Questions and Answers 2009*

Questions are shown below in **bold** and answers are selected student responses that received full marks. (Learning Goals and Topic-level Goals are matched from Table 2.3)		
Instructions to Students: Answer the following questions the best that you can (individually and in groups). Draw on your science background to help. If you don't know the answer – write that you don't know. This is not graded, but used for research in your learning. *GOAL:* To assess your previous knowledge of mineralogy		
Question 1: What do you think a diagnostic property for identifying minerals is? Explain in as much detail as you can, giving a relevant example. (2 marks) Ideal student response: "It's a physical property that's unique to the mineral and helps us identify it in hand sample. Example: cleavage; in amphiboles you can sometimes see characteristic 60-120 degree cleavage, in two directions."	**Learning Goal:** 4, 6	**Topic-level Goal:** 2
Question 2: Diamond and graphite have very different properties. I) What is the main reason for their differences? (1 mark); II) What environment do you think diamond forms in? What about graphite? (2 marks) Ideal student response: *I.* "The main reason is their crystal structures are different due to the different environment each forms in" *II.* "Diamond forms in a high pressure, high temperature environment, probably much deeper in the Earth. Graphite forms in shallow crustal conditions, with lesser temperature and lesser pressure."	1, 2, 3	1
Question 3: What are some minerals harder than others? (1 mark) Ideal student response: "Some minerals are harder than others because they are held together by stronger atomic bonds (e.g., covalent versus van der Waals bonding) within their crystal structure."	1, 2, 3, 6	1, 2
Question 4: Name two physical properties that differ between the Carbonates and the Sulphides. Explain (2 marks) Ideal student response: "1. Specific gravity – Sulphides tend to be heavier than Carbonates, 2. Streak – Sulphides tend to have dark-coloured streaks, while Carbonates have white or colourless streaks."	1, 2, 3, 4	1
Question 5: Wollastonite's mineral formula is: $CaSiO_3$. Aragonite is $CaCO_3$. What is the Anion and what is the Cation for each? (2 marks) Ideal student response: "Wollastonite: Cation = Ca^+, Anion = SiO_3^- ; Aragonite: Cation = Ca^+, Anion = $CaCO_3^-$."	1, 2, 4	1
Question 6: Why are phyllosilicates typically very soft minerals? (1 mark*)* Ideal student response: "They have weak bonds between strongly bonded sheets of silica tetrahedra with OH^- and H_2O molecules in-between the sheets as well."	1, 2	1, 2
Question 7*: What is the unit cell of a mineral? Explain (2 marks) Ideal student response: "It is the building block of a mineral. It's the smallest, simplest, unique, representative structure of the mineral which is repeated (in 3D) to form a mineral."	1, 2	1
* In 2008, the order of questions was different and Question 7 was replaced with another question: **Question 7: You've collected several samples of an unknown mineral. You have used your identification techniques but still can't identify it. Describe the process that you would go through to identify the mineral. (2 Marks)** Ideal student response: "I would use an analytical technique such as X-ray Diffraction. You can crush the sample and use the machine to match your sample to known mineral compositions and structures."	5, 6	1, 2, 3

2.4 RESULTS

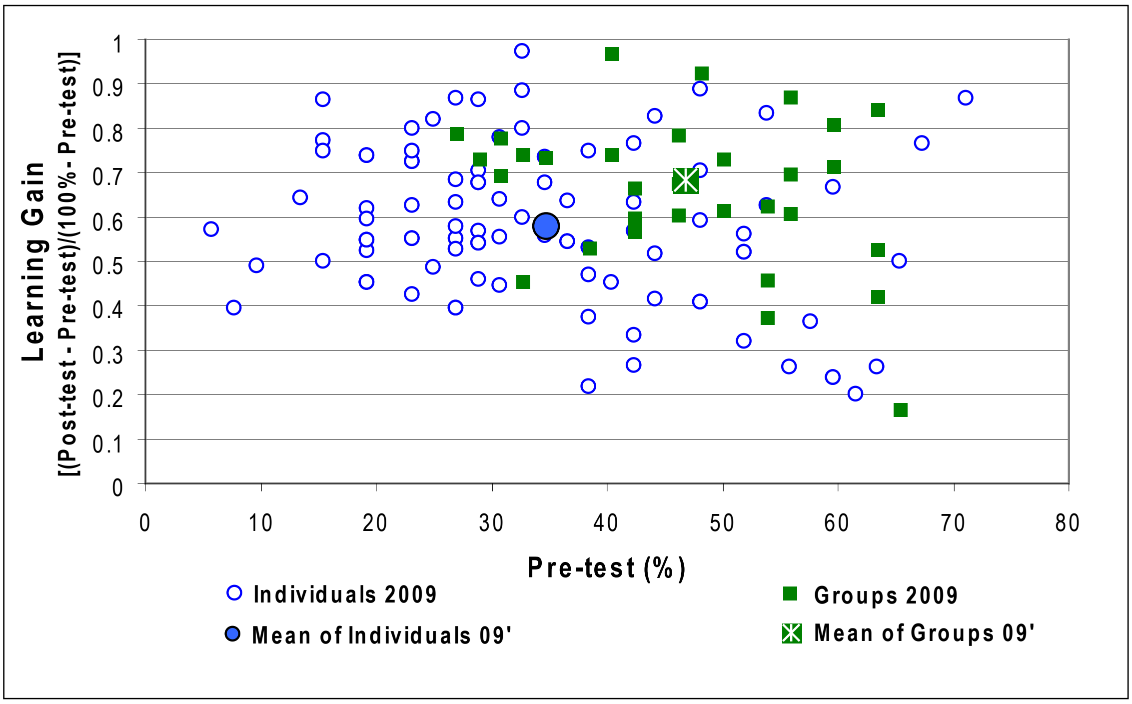
Results from this study show that: 1.) Learning gains recorded from pre- and post-test results in both semesters are systematically greater in the groups than for the individuals; 2.) Groups of four proved to be the optimal size in this curriculum and 3.) Student feedback from both semesters improved significantly and elicited small changes to the laboratory format and assessments in the 2009 and future curricula.

2.4.1 Individual and Group Learning Gains

Results from the pre-post tests in 2008 and 2009 indicate that students gain some conceptual knowledge throughout the semester. Figure 2.2 illustrates a plot of the calculated learning gain (Hake 1998) versus the pre-test scores. This plot also shows that our pre-post test instrument was "too easy" (individual students and groups scored 70-80% on the pre-test; with learning gains of 0.8-1). In addition, some groups scored 100% on the post-test, achieving an unwanted "ceiling effect" which does not allow a true learning gain to be calculated for these students. The ceiling effect resulted in a non-Gaussian distribution of scores which limited our ability to perform statistical tests on the pre- post-test data.

Most importantly, the clustering and the average normalized learning gains from each series of data indicate that groups systematically performed better than individual students. In order to better understand this observation, we looked at individual student success compared to the group in the pre-post test scores. Two factors were explored that could impact group success: group make-up (i.e., a grouping of similar or mixed-talent achievers) (Appendix C); and group size (Figure 2.3; 2.4).

Figure 2.2: Results of pre- and post-tests from 2009. This graph illustrates the calculated individual student and group normalized learning gains (Hake 1998). The mean of the learning gains have also been plotted. These data illustrate that the instrument was relatively 'easy' because some students achieved higher pre-test scores than expected and that groups scored systematically higher than the individuals.

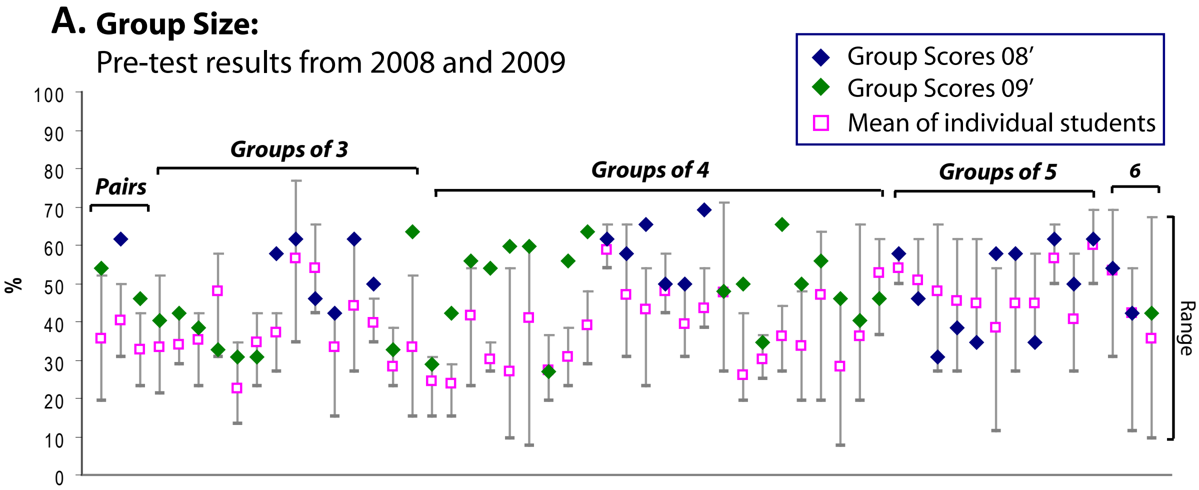


Students were assigned into low-, medium- and, high-achiever talent categories based on their final course grades in 2008 and 2009. Criteria for assigning students to specific categories can be found in Appendix C. Plots (Appendix C, Figure C1.B) and statistics (Appendix C, Figure C1.C) of group scores, the range and mean of individual student scores did not illustrate a correlation to group success when sorted into mixed-talent (e.g., L, M, H students) or same-talent (e.g., M, M, M students) groups.

Figure 2.3A compares plots of individual group member grades with the group scores of the pre-tests in 2008 and 2009, sorted by group sizes of 2 - 6. We utilized a metric to define the 'success' of collaboration within a group when the group score exceeds the top student's score (Michaelsen, Bauman Knight and Fink 2004). Figure 2.3B is a table of statistical values calculated from comparing the pre-tests of individuals within the group, including group success. Individual post-test data was not collected in the 2008 semester and was therefore omitted. Groups with two, three and four members had group scores that exceeded top-student scores and were therefore defined as 'successful' collaborative groups.

Although, for groups of two this may be an artefact due to the small number of pairs (n=3). Generally, our data indicate that groups with four students may work more collaboratively (group sizes of 5 and 6 were shown to be less successful than group sizes of 2 to 4 students).

Figure 2.3: Comparing group scores to individual students within the group. A. A plot of the group scores, with the range and mean of individual students also shown from pre-tests in 2008 and 2009. Each group is segregated on the x-axis, and are sorted by group size. B. A table illustrating relevant statistical values associated with group size.



B.

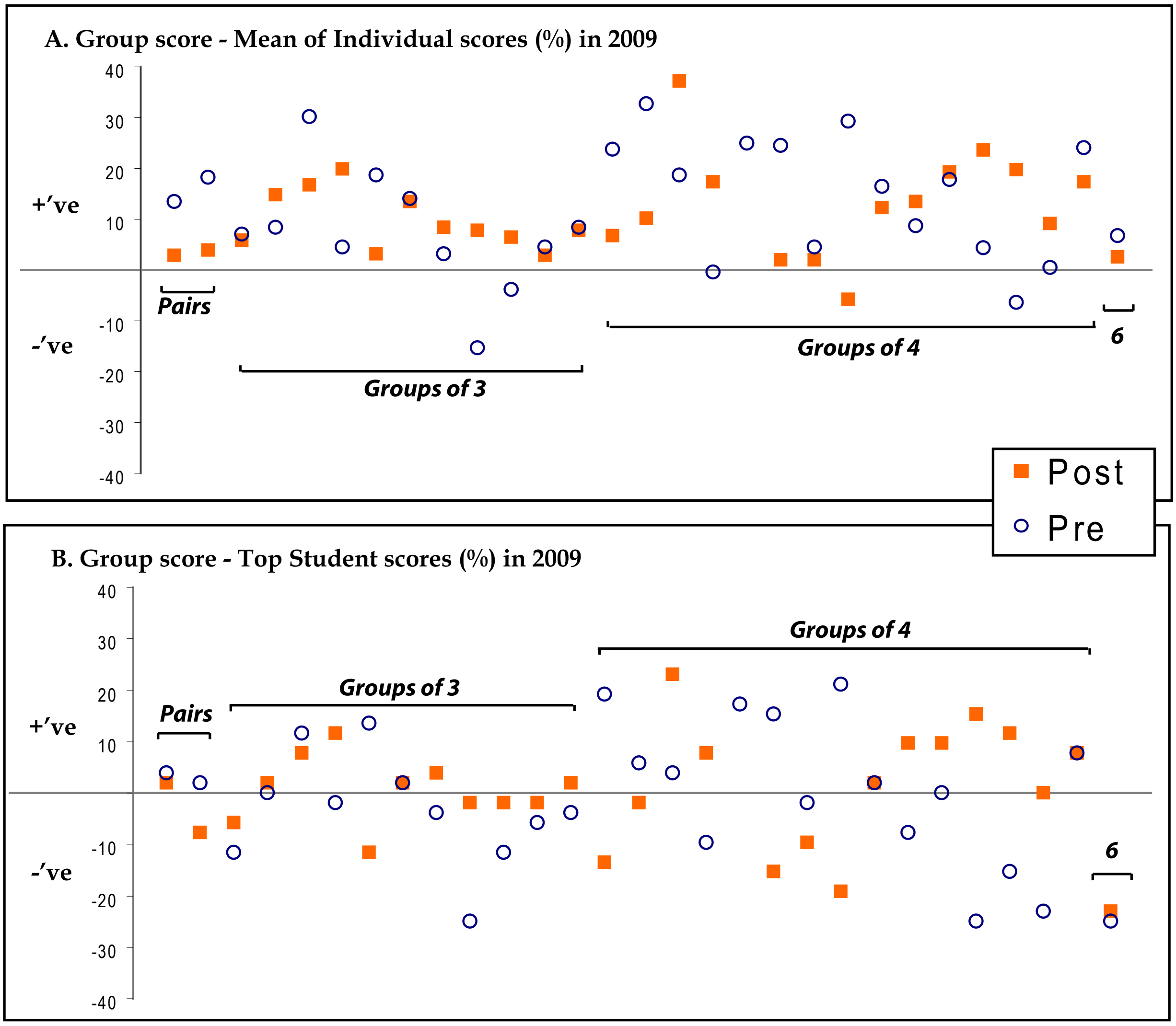
Group Size

	2	3	4	5	6
n=	3	17	21	11	3
Group Scores	53.85	44.57	52.84	48.25	46.15
Mean of Individual Students	36.22	36.69	38.71	47.98	43.70
Top Student	48.08	47.62	51.83	60.84	63.46
Range	23.72	23.30	26.74	25.87	46.15
Group - Individual Students	17.63	7.88	14.13	0.27	2.46
Group - Top Student	5.77	-3.05	1.19	-12.59	-17.31

Figure 2.4A illustrates the differential change in group scores minus the top student score in pre-post tests for each group in 2009. A mean positive differential for all groups, indicate that group work yielded a higher group score than the top scoring student (Figure 2.4B). A comparison of the means of the differences between pre- and post-test 'success' could indicate a change in collaboration within groups *during* the semester (Figure 2.4B). A positive change (or a more positive differential) in the post-test versus the pre-test is interpreted by the group exceeding the top student scores. This means that collaboration has paid off and the group effort has led to positive changes throughout the semester. However, some groups of three and four illustrate very negative changes.

In general, the post-test differentials for most group sizes are larger than the pre-test values, suggesting that collaboration may be becoming better over the term and resulting in group achievement. Groups with four members displayed the largest positive differential, a larger range in differentials and dominantly positive changes throughout the semester. Within the group size, the larger range is an artefact of the number of members per group (i.e., a group of four has more members than group of three, which results in a larger positive and negative differential values). While a group size of three illustrated less overall positive differentials (compared to a group size of four) and showed significant, incremental positive changes (Figure 2.4B: group three had 8 groups with positive changes and 2 with negative changes during the term).

Figure 2.4: Group performance changes throughout the term. A. Differential between the Group and mean scores of each group. Positive values indicate collaboration (group score exceeds the average effort from the group; Michaelsen, Bauman Knight and Fink 2004), and negative indicate the opposite. B. Difference between the Group scores and the Top student scores. This also indicates collaboration, to a higher extent (group score exceeds the top student's score). C. Means of the differential shown in A, and B. Note that group size of 4 is consistently more positive, with the largest range of values, and that overall differentials are positive indicating collaboration is occuring in all group sizes.



C. Table of the Mean of Differentials shown in A, and B.

	Group size 2		Group size 3		Group size 4		Group size 6		Overall	
Mean of…	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Group - Mean of Individual Students	15.87	3.37	7.23	9.70	14.87	13.14	6.73	2.56	**11.76 ± 11.8**	**10.71 ± 8.74**
*Range**	*4.81*	*0.96*	*45.51*	*16.99*	*39.10*	*42.95*	*N/A*	*N/A*	*48.07*	***42.95***
Group - Top Student Score	2.88	-2.88	-3.32	0.52	0.64	1.92	-25.00	-23.08	**-1.59**	**0.14**
*Range**	*1.92*	*9.62*	*38.46*	*23.08*	*46.15*	*42.31*	*N/A*	*N/A*	*46.15*	*46.15*

* Statistically, group sizes of 3 and 4 will have a larger range due to higher n values

2.4.2 Positive Student Feedback

Data from anonymous student feedback surveys (multiple choice and open-ended questions) were collected in order to assess students' attitudes to the curriculum and specifically the use of group work. Average responses were calculated by taking the average and standard deviation of individual responses on a Likert Scale (1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree and 5 = Strongly Agree). Figure 2.5A shows the results from an end-of-term survey in 2008. Students were positive about the laboratory format and style (Figure 2.5Aii), MinBook (Figure 2.5Ai: Question 4) and individual assessments (Figure 2.5Ai: Question 6; Figure 2.5Aii). A large proportion of students felt that the Poster Session used in 2008 was not useful for their learning (Figure 2.5Ai: Question 5) and was subsequently removed from the 2009 curriculum. One student commented, "I felt it was a waste of time: it was very tedious and time consuming". The MinBook project was also altered due to feedback. Most students felt it to be a very worthwhile exercise (Figure 2.5Ai: Question 4), but that it took many extra hours outside class: "It required a lot of work and I spent more time making it than I did studying it". Therefore, the minerals included in the project were reduced from 55 to the most common 20 rock-forming minerals.

In both years, the majority of students valued the use of group work (Figure 2.5Ai: Question 1; Question 2; Figure 2.5Aii). One student stated, "I enjoyed the group work in the laboratory. I found discussing/working through the answers to the laboratories and quizzes very helpful in understanding the course material". The graph of survey responses in Figure 2.5Aii shows that the two elements of the course that the students most wanted to keep were group format and the laboratory format and style.

Based on observations from teaching assistants in both terms, some additional changes were made. In 2009, we awarded students 3% credit at the end of term if they had completed all the questions in the laboratory manual. Teaching assistants also expressed support for the group format. They indicated that the use of their time in the laboratory was more efficient and that marking hours were within pre-determined limits.

In 2009, we decided to recommend group sizes no greater than four due to some negative group dynamics informally observed in larger groups of five and six. Negative group dynamics included segregation of members and disengagement of some students. These observations were later supported by the low differential (group-top student) values or negative changes shown by some groups (Figure 2.3B and Figure 2.4A).

After minimal changes to the laboratory curriculum as discussed above, student feedback collected from a midterm survey from 2009 was also very positive (Figure 2.5Bi and 2.5Bii). Students found some aspects of the laboratory challenging, such as the mineral identification and memorizing mineral properties (Figure 2.5Bii), but continued to find the laboratories (and the format) useful for their learning (Figure 2.5Bi: Question 1). Group quizzes were also reported to have helped with their learning (Figure 2.5Bi: Question 2), but informal feedback from one of the teaching assistants indicated that some groups were malfunctioning: “Some groups were not very collaborative in their group quizzes. In these groups there were often one or two students who answered all the questions and didn't consult or even allow contributions from other group members. This was particularly obvious if certain group members were more interested in finishing the laboratory early whereas others actually wanted to learn the content”.

Although the weekly group quizzes were each worth 1% (of their total grade), some students resented the use of this format of assessment. One stated that: “It is good to discuss in a group first, but at the same time, we disagree on some answers and the answer I would've written down if I were to do it myself is different from the group answer. Sometimes I feel like this is unfair because my answer was actually right but instead I lost marks since it was to be a group effort”.

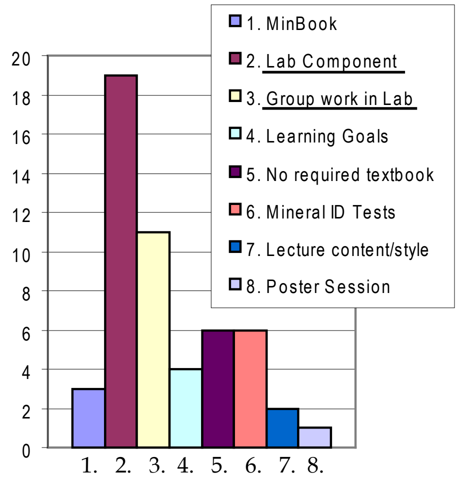
Figure 2.5: Graphs and multiple-choice questions illustrating positive student feedback collected from 2008 (A.) and 2009 (B.).

A. *2008*

i.)

Multiple Choice Questions Likert Scale (5 = Strongly Agree, 1 = Strongly Disagree), n=55	Average response ± σ
Question 1. Working in groups in the lab was useful to my learning.	4.34 ± 0.88
Question 2. The group quizzes in lab were useful to my learning.	3.54 ± 1.01
Question 3. My lab group worked very well together.	4.25 ± 0.84
Question 4. Constructing the MinBook was useful for my learning.	3.54 ± 1.09
Question 5. The Poster Session was useful for my learning.	2.71 ± 1.20
Question 6. The Mineral ID tests were useful for my learning.	4.02 ± 0.88

ii.) If I could keep one thing the same about this course, I would keep... (*n=52; Open-ended response, collated*)

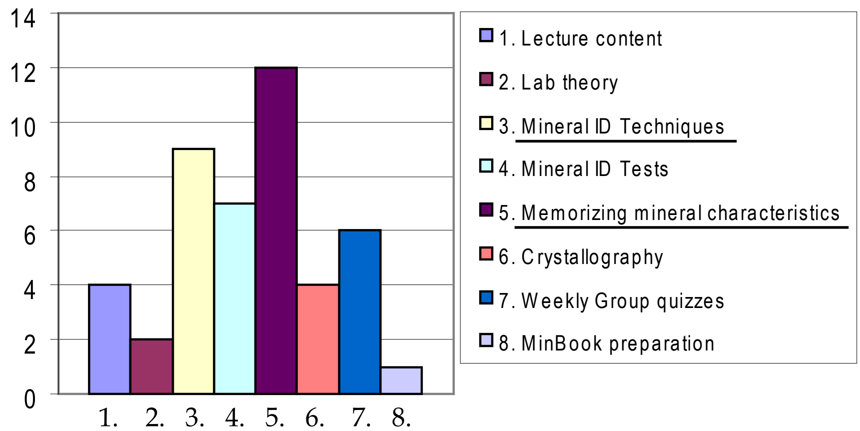


B. *2009*

i.)

Multiple-choice Questions (5 = Very Much, 1 = No help), n=49	Average Response ± σ
Question 1: How well have the labs facilitated your learning in this course?	4.58 ± 0.68
Question 2: How well have the group lab quizzes facilitated your learning in this course?	3.86 ± 1.14

ii.) The aspect of this class that has been the most challenging for me has been... (*n=45; Open-ended response, collated*)



2.4.3 Limitations and Sources of Error

The methods of this study and use of the pre-post test instrument does allow for some notable sources of error. Primarily, the pre-post test was not rigorously validated and as a result was 'too easy', so learning gains and individual and group results should be considered with caution. In 2009, Dohaney marked all of the tests, while in 2008, teaching assistants also marked the post-test results. Even though a marking rubric was used, the results of these scores may be skewed based on the expectations of the markers. Lastly, when considering the group size impact, it should be noted that statistically we did not have enough group sizes of 2 (n=3), or 6 (n=3) to make accurate observations regarding their performance.

2.5 FACTORS THAT AFFECT GROUP WORK

Group learning has often been shown to be instrumental in student achievement and positive attitudes towards learning (Springer, Stanne and Donovan 1999), but has some limitations. Our results from pre-post tests showed that group learning was effective overall and indicated that group size is a factor that may affect group 'success', but that group make-up was not a factor in this curriculum. The level of collaboration can be affected by other factors such as the individually-assigned 'worth' of the group assessments and TA attitude and behaviour towards group work.

2.5.1 Group Size

Groups of different sizes can have different group dynamics and this affects the level of collaboration achieved. We observed that when the groups were in disagreement, or if there were significant personality clashes, smaller groups created a "get on with it" mentality while larger groups tended to segregate into pairs, becoming less collaborative. Research indicates that small groups (three and four students) have been successful for shorter assignments such as problem-solving exercises (Heller and Hollabaugh 1992), while larger groups are more appropriate for complex, long-term and out-of-class assignments (Bales 1967). Other research has shown that as groups become larger, fewer members actually participate in the group discussions (Bales 1967) and in some cases display more off-task behaviour (Maskit and Hertz-Lazarowitz 1986); and as a result, members may feel less satisfied and less committed to the success of their group. We found that small groups (three and four students) are more effective than larger groups in this laboratory curriculum (five or six students), but more data is needed to validate this observation.

2.5.2 Group Make-up

Some studies indicate that the make-up of groups affects learning and collaboration. Some state that heterogeneous groups (where students are of mixed abilities; high- and low-achievers) are more beneficial than homogenous groups (Webb 2010); while other studies indicate that heterogeneous groups with large differences in talent (e.g., a group containing a student of a much higher ability) may inhibit total group performance (Nihalani et al. 1990) and encourage dysfunctional behaviour. To avoid negative group dynamics within heterogeneous groups, using peer-evaluations can enhance a group's ability to work together by helping students identify group weaknesses and strengths in their abilities (Barron et al. 1998; Beichner et al. 2000) and helping them to relate to one another.

Regardless of group make-up, it is accepted that low-achieving students can achieve learning gains (Giuliodori, Lujan and DiCarlo 2008; Macpherson, Lee and Steeples 2011) and best practices (Nihalani et al. 2010) from group work. However, our data did not indicate a significant difference between heterogeneous and homogenous talent groups within this curriculum format.

2.5.3 Worth of Group Assessment

Increasing the marking value (or worth) of the group assessment could motivate some students to engage (Karau et al. 1993; Cortright et al. 2003; Webb 2010) and thereby enhance the productivity of the group. However, it is also likely that increasing the worth of the group assessments may cause more students to resent the use of group work. Task or assessment worth is individually defined (Ryan and Deci 2000; Eccles 2005) and several students indicated in the feedback surveys that they felt group quizzes were an unfair way to assess their individual efforts.

2.5.4 Teaching Assistant 'Buy-in'

Teaching assistants should be more vigilant to noticing negative group dynamics such as disengagement and "free-loading". The attitude of the TAs can affect laboratory learning environments and communication of content to the students. Goertzen, Scherr and Elby (2009) found that TAs who "buy into" the method and style of teaching used, are more likely to convey their respect for the material and the teaching process to the students, as well as learning more themselves. We used weekly meetings with the TAs to review the mineralogy content being taught and troubleshoot any issues occurring during the term. We found these meetings to be invaluable for establishing positive, unified teaching strategies among our graduate students. Positive attitudes about the group learning strategy from TAs can help students accept this format more readily and foster a more successful learning environment.

2.6 CONCLUSIONS

Based on positive student feedback and increased learning gains, we will continue to utilize the current curriculum design for our introductory mineralogy course. Organization of learning material, use of customized projects and group learning strategies have all been shown to be successful in this laboratory format. Based on pre-post test results, group work led to better student performances individually and as a group. This course will limit the group size to three or four students based on the results of this study and we suggest that similar laboratory formats (e.g., Petrology or Introductory Geology) could also benefit from group learning.

Students continued to have difficulty with the amount of memorization that they perceive is necessary for this course. Like all other descriptive sciences, Mineralogy requires a detailed observational and textural vocabulary to describe and identify minerals. We can help our students by encouraging them to practice these skills together so that the new vocabulary and mineral names become a part of their geological lexicon. Because using group assessment for this is unfavoured by some students and if smaller class numbers are available, then paired learning may be a more positive learning experience for some. The opportunity for peer-learning is invaluable to their development of social, practical and intellectual skills that are needed in the "real world". By helping, practicing and strategizing with each other, they can overcome the challenges that students face with understanding mineralogical theory.

CWSEI continues to assess this course (lecture and laboratories) as a part of its departmental effort to improve geoscience education (Carl Wieman Science Education Initiative 2009). A copy of the laboratory materials and other content written and designed for this course is available from the first author.

CHAPTER 3: FIELD NOTE-TAKING AND PERCEPTIONS: TOWARDS CLASSIFICATION AND BEST PRACTICES

PREFACE

(Artwork by Elle Emery)

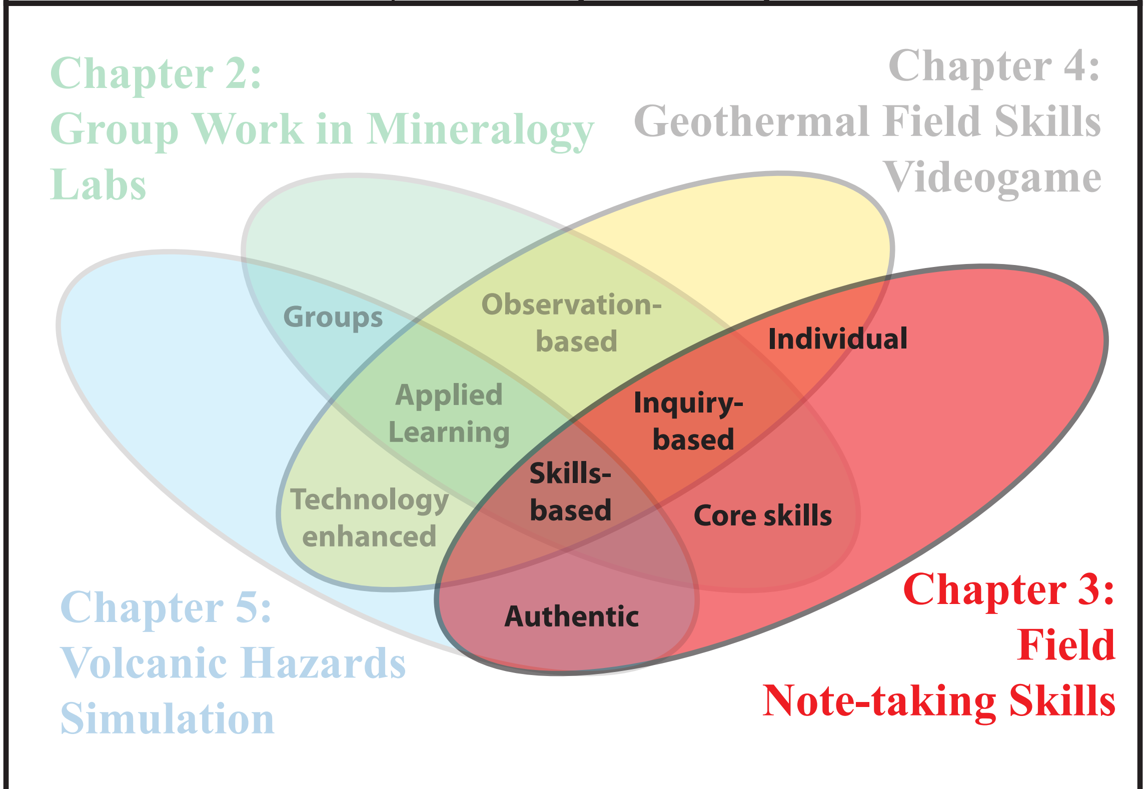
The work from Chapter 3 was done to try and ascertain how geologists behave at 'the outcrop' and how to translate that into teaching and learning practice. This study is interrelated to the next chapter (Chapter 4), as the research and data collected were undertaken simultaneously and with similar learning goals. This chapter continues with the ***Constructivist paradigm*** which has been traditionally taught within the field teaching strategy utilised in this discipline for more than a century.

Making and ***recording observations*** into field notebooks are among the primary ***skill*** sets that novice geologists must acquire for their professional and academic careers. These observations are the ***data*** that a geologist uses to make hypotheses and record changes in the landscape from one location to the next. These ***core geoscience skills*** are needed in academia and the workplace.

Chapter 3 is an in-depth look at the art and science of note-taking in the field. We began ‘from scratch’ as there was no previous academic research published on note-taking in the geosciences. Note-taking is an ***individual inquiry-based*** activity that takes place an ***authentic*** field environment. Theory from classroom note-taking and educational psychology topics provided a foundation for our study. The educational theories include ***cognitive load theory*** and ***novelty space*** theories. The learning strategies and theories discussed in Chapter 3 are shown in Figure 3.1. We probed into student notebooks, behaviour and field teaching literature in order to develop ‘best practices’ for note-taking. These best practices have been distilled into useful, practical teaching advice for geoscience and other natural science field teachers.

Figure 3.1: Theoretical concepts (top) and learning strategies (bottom) which are discussed in Chapter 3.

	Chapter 2	Chapter 3	Chapter 4	Chapter 5
Goals-based Curriculum Design	✓	✓	✓	✓
Authentic Learning Environment		✓	✓	✓
Cognitive Load Theory	✓	✓	✓	✓
Novelty Space		✓	✓	



3.1 INTRODUCTION AND RESEARCH QUESTIONS

Research shows that field trips offer valuable opportunities to learn theoretical geoscience concepts (Kern and Carpenter 1986; Kent, Gilbertson and Hunt 1997; Elkins and Elkins 2007) and instructors regard geoscience field work as “essential to learn the kinds of observations on which our entire field is based” (Butler 2008). However, there is a paucity of rigorous education research on practical skill development, such as note-taking or field observations. In a recent survey, geology professionals in Canada valued practical *Field ‘Skills’* above all other aspects of the undergraduate geology curricula (Jones et al. 2010). In addition, a lack of departmental funding and increased student numbers in many field-based sciences (Gold and Haigh 1992; Bradbeer and Livingstone 1996) have commonly lessened the number of field courses and the total time spent in the field, which results in graduates with less practical field experience and skills.

In this study, we characterized students’ field note-taking abilities through observations and analysis of student notebooks and students’ perceptions of note-taking through qualitative analysis of focus group data. Butler (2008) describes notebook skills as: “... the practice of keeping a notebook as a document of scientific research, where hypotheses, methods, data, observations, interpretations, hypothesis modification and planning the rest of the task are distinctly and systematically laid out.” Although note-taking skills are fundamental in the geosciences: “there are no hard and fast rules over how to write field notes” (Nicholas 2000) and many degree programmes do not explicitly teach note-taking methods (Van Meter, Yokoi and Pressley 1994). In the geosciences, like other field sciences, note-taking is commonly learned via holistic, piecemeal ‘best practices’ passed down from various lecturers in different sub-disciplines (Emerson 1995), or through an ‘apprenticeship’ where a student studies under an experienced professional in the field setting. Additionally, the rapid changes in lecture style and information delivery using educational technology is causing some students and lecturers to perceive note-taking in the classroom, or any setting, as an obsolete skill (Van der Meer 2012).

This study aimed to characterize students' notes and their note-taking experience and behaviour in a naturalistic, introductory field lesson. Our research questions included:

- What effect do previous field and coursework experience (geoscience or similar-disciplines) have on students note-taking?
- What are students' perceptions of taking notes in general? Are these congruent with their behaviour?

This paper begins with a detailed outline of the field experiment, participants of the study, semi-quantitative and qualitative note-taking results, a discussion of the factors and strategies that students employed during note-taking and concludes with pedagogical suggestions for practitioners.

3.2 LITERATURE REVIEW: THE 'FIELD' AND NOTE-TAKING

Observing and recording data from natural phenomena are regarded as primary skills for field geologists (noted amoung other commonly taught field skills in Nicholas 2000). Many geologists may think that field trips are the best (and possibly only) way to teach certain concepts and skills in geology but "… effective learning cannot be expected to follow just because we take students into the field" (Lonergan and Andresen 1988). Field-based educational research aims to understand what cognitive, behavioural and social elements affect learners in this authentic environment (e.g., Orion 1993; Orion and Hofstein 1994). A summary of pertinent findings is included below, to set the foundation for our understanding of the note-taking 'environment'.

3.2.1 Field Pedagogy, Cognitive Load and the Field Environment

"Fieldwork gives opportunities for learning which cannot be duplicated in the classroom. It greatly enhances students' understanding of geographical features and concepts and allows students to develop specific as well as general skills" (Her Majesty's Inspectors 1993). There are many interconnected pedagogical and logistical factors that can influence the effectiveness of a field trip (Maskall and Stokes 2009; Stokes and Boyle 2009). Vick, Boardman and Henrickson (1979) suggest that traditional geology field trips use a 'show-and-tell' method focused on introducing a variety of phenomena and concepts (many geologic features) rather than teaching students to observe and reason. In 'show-and-tell' style fieldtrips, students have a tendency to reproduce the lecturer's viewpoint unquestioned rather than their own unless prompted to do so (Haigh and Gold 1993). Fieldtrips should focus on self-determined activities where 'making accurate and detailed observations and interpretations' should improve transfer of skills necessary for application to any geologic scenario (i.e., transferable 'field' skills) (Vick, Boardman and Henrickson 1979). The observations students typically make at field sites can be characterized as progressing from the 'large-scale' to the 'small-scale' (Vick, Boardman and Henrickson 1979). Field trips can be designed as individual, paired, grouped or class exercises; carried out during one day to entire months of fieldwork.

Note-taking in the field is a complex task and requires students to simultaneously *select* information from the task environment, *maintain* and *integrate* this information with new and old ideas and then *organize* and *record* these notes into a notebook. All these cognitive skills use working memory. Studies show that students with 'low' working memory can become 'debilitated' by note-taking (Di Vesta and Gray 1973; Kiewra and Benton 1988). Cognitive load theory is the current understanding of how cognitive 'resources' are managed during learning and problem solving tasks (Sweller 1988). The cognitive load imposed by authentic 'real-life' learning tasks is often excessive for novice learners (van Merriënboer and Sweller 2005).

Cognitive load theory suggests that when learning new material, an individual's working memory can store seven elements, but can manipulate only two to four elements at given time (Sweller, Van Merriënboer and Paas 1998). 'Experts' of a given topic store information in organized, complex, 'big idea; structures, called *schemata* which are stored and accessed rapidly (Bransford, Brown and Cocking 2004). Expert's *schemata* are treated as 'one element' rather than many and therefore experts can handle more complex working problems (van Merriënboer and Sweller 2005), whereas 'novices' do not yet have these schemata and struggle to handle many new concepts simultaneously (van Merriënboer and Sweller 2005). Concept rehearsal can enhance the storage of working memory (Sweller, Van Merriënboer and Paas 1998). Extraneous, or off-task information provided to the learners may increase the overall cognitive load and decrease the relevant 'on-task' working memory (Chandler and Sweller 1991).

The field environment presents a learning challenge even to the expert geologists: "The field bombards our senses, challenging all our perceptual mechanisms" (Lonergan and Andresen 1988). Orion and Hofstein (1994) built on the concept of cognitive load and introduced the concept of 'Novelty Space' as having a major impact on field learning. '*Novelty Space*' is a measure of how unfamiliar the environment and learning tasks are to the student learner and thereby an additional component of cognitive load. The field is composed of 'novel' cognitive, psychological, social, geographic and environmental variables. Students with very little preparation (i.e., high novelty space) will be unable to cope with the authentic, stimulating environment and execute problem solving and reasoning tasks at the same time (Orion and Hofstein 1994). Subsequently, they will spend a large proportion of the field trip 'off task'.

Researchers in other scientific disciplines have noted similar field trip phenomena (e.g., biology, Cotton 2010).

3.2.2 Previous Educational Research on Note-taking

Educational research on note-taking focuses on classroom environments, with many studies illustrating the learning benefits of note-taking in the classroom (Crawford 1925a; Crawford 1925b; Di Vesta and Gray 1972; Di Vesta and Gray 1973; Carter and Van Matre 1975; Peper and Mayer 1978; Ganske 1981; Einstein, Morris and Smith 1985; Kiewra et al. 1995). We found no studies in the geoscience education literature on note-taking skills in the field.

Researchers show that (classroom) note-taking involves two major cognitive functions: *encoding* and *storage* (Di Vesta and Gray 1972; Kiewra 1989). Encoding is a crucial initial process that involves transcribing the notes. Encoding assists learners to build connections between their prior knowledge and the new information (Peper and Mayer 1986). Storage involves the reviewing or rewriting of notes after the initial encoding session. Storage appears to be more successful than encoding as the act of reviewing notes appears to reinforce in-class concepts and provide the learning benefits (Kiewra 1985).

Encoding can be impeded by several pedagogical aspects; most commonly high lecture pace and high information density (Peters 1972; Aiken, Thomas and Shennum 1975; Van Meter et al. 1994). The resulting high cognitive load means that students cannot process the information effectively (Kiewra 1989). We suspect that encoding issues are exacerbated by the field setting due to its high novelty space.

Van Meter et al. (1994) verified some of the extant note-taking research such as effects of pedagogy and student note-taking strategies (e.g., students adapting their note-taking strategies to maximise perceived successful outcomes, such as assessment opportunities). Ganske (1981) highlighted the importance of previous knowledge of a subject and note-taking performance. He described note-taking behaviour as being categorized into two end member groups. Category 1 (or 'processors') students wrote dominantly unorganized, paraphrased (unique) notes, with low values of completeness (proportion of material included), while Category 2 (or 'transcribers') wrote word-for-word, verbatim, complete information which was well organized and easily read by others. Following the work of Ganske (1981), Barnett and Freud (1985) qualitatively analyzed notes of students and found that learners both with and without background knowledge recorded *verbatim* notes, but that the notes of students with previous background knowledge were more *unique* (i.e., paraphrased).

3.2.3 Working Definition of Note-taking Best Practices for the Geosciences

We propose that taking notes in the field environment differs from classroom note-taking in several important ways: a) encoding is of a greater complexity in the field setting as observations must be understood, *verified*, organized and recorded; b) storage occurs on-the-fly in order to formulate 'working models' and hypotheses in the field c) note-taking occurs in an informal, authentic field setting (e.g., the notes are not illustrated and the lecturers statements are not rehearsed); d) language used in the field is less formal and topics are commonly less organized than the classroom; and e) there are individualistic and subjective aspects of field note-taking (i.e., students are encouraged to write what *they* see, not what the *lecturer* sees). Most importantly, aside from listening and encoding, the student should be independently *verifying*, *scrutinizing* and *comparing* information at a given location.

Discussing observations, processes and interpretations together throughout a field lesson is also a frequent practice of geology lecturers. It is expected that the student should recognize and be able to discriminate between observations and interpretations. These additional cognitive processes increase the intrinsic cognitive load of field note-taking. Orion and Hofstein (1994) recommend having preparatory activities prior to the field trip to reduce the effects of novelty space (and thus cognitive load) in order to improve student attitudes to allow students to proceed with the academic task at hand.

The teaching of note-taking skills in the geosciences, when taught, is commonly embedded within a field course of a given topic (e.g., sedimentology or volcanology). The approach, measurements, items of interest and descriptive language recorded at a given geologic locality can be quite specific to that subdiscipline. A skilled geologist (academic or practitioner) should have a well-established approach and a set of best practices that are useful in any geologic environment. Methods included in common field geology teaching texts recommend general practices in which students are instructed. The following excerpt is taken from Compton (1985) comprehensive ‘Geology in the Field’:

> All observations and interpretations are recorded in field notes... Notes can be kept from becoming verbose or illegible by use of [abbreviations]... Each page of notes must be numbered consecutively for a given notebook or project and must be headed by the geologist’s name, the date... The descriptive parts of the notes should present facts and thus be kept free as possible from terms that are [interpretive]. Interpretations interwoven with descriptions must be identified clearly so that they will not later be read as facts. Rocks and structures identified with certainty can be given firm names, but other identifications should be ... simply stated as unknowns.
> (Excerpt taken from Compton (1985); NB: Compton is referring to note-taking as an independent exercise rather than as a student attending a Lecturer-guided Lesson)

This excerpt represents the range in content and formatting considerations a geologist will encounter when writing notes in the field. Fundamentally, note-taking should be completed in a way that allows other geologists to read and document a field site accurately and completely.

3.2.3.1 A Word on Geoscience 'Expertise'

Current research on the spectrum of geoscience expertise (e.g., Petcovic and Libarkin 2007) shows that geologists are commonly presented with decisions in the field; primarily in data-poor scenarios and that expertise plays a crucial role in success of fieldwork (Bond et al. 2007). An instrument currently in use to assign a participant within the field mapping expert-novice expertise spectrum (Callahan, Petcovic and Libarkin, Pers comm) has two separate scales: one for general geology expertise (courses taken, degrees achieved, professional work experience) and field mapping expertise (field courses, field research and field work experience). Using these parameters, the students of this study are all considered 'novices', as they rank low in experience on both scales, compared to a professional (e.g., mining) or academic geologist but should not be interpreted as students mastering general field mapping skills, but specifically referring to note-taking.

3.3 EXPERIMENTAL DESIGN

In a comprehensive study, Bonner and Holliday (2006) used student interview data and detailed analysis of the content of students' classroom notes to investigate student note-taking behaviour. In this study, we set out with a similar intent and methods. The mixed methods study recorded video of two different field lessons (two lecturers and the same learning outcomes), administering a pre-experiment questionnaire to collect student demographic information, collecting the students, 'notebooks' (a paper-based instrument) and interviewing students set in a focus group setting five months after the note-taking activity. The following sections describe the participants of the study, the field location and lecturer pedagogy, data collection methods and the metrics developed in this study to apply semi-quantitative analysis to the coded notebooks.

3.3.1 Student Participants

The participant's demographic information was collected via a short, open-ended questionnaire. The student participants (n = 42) in our study were enrolled in a 2 to 5 week pre-semester field course which was designed to provide students with an introduction to advanced field techniques (i.e., 300- or 400-level) in volcanology and geothermal topics. The student participant population included both genders (female = 18; male = 24), different nationalities (Netherlands (1), United Kingdom (1), New Zealand (9), United States of America (31)) and age. Most students were between the ages of 19 - 21 with a smaller group of students between the ages of 22 - 46 (n = 7). The field course accepted students with no prerequisites and therefore the population ranged in geologic backgrounds from environmental science students (n = 8) to engineers (n = 8), who had no formal field or coursework geology training, to geology students (n = 26), who were classified as having 'some' or 'lots' of field experience. We assigned them to these categories based on a combination of the number of field trips, the number of days in the field (total) and whether they have had independent research experience (e.g., summer internships) prior to the study. The students who were assigned to the 'lots' category had more than 3 field trips and/or more than 20 days in the field and any independent field experience.

Several students reported having previously completed summer research internships (n = 9), either in New Zealand or the United States. This range of 'expertise' provided a rare opportunity to test a breadth of geology undergraduate skill sets and perceptions. Additionally, 6 of the participants had previously taken a hydrogeology course, which contained a module focused on geothermal concepts (the topic of the field trip in this study, see below), but did not have a practical-based field component.

3.3.2 The Geothermal Field Setting & Lecturer Pedagogy

The note-taking study occurred over two days at a well-known New Zealand geothermal tourist site. The site was a typical field setting, with easy access (via a boat and boardwalk) and low topography. Prior to the activity, information about the study was presented to the students and consent was granted by the participants in accordance with the University of Canterbury's Human Ethics procedures (Refer to Appendix B2).

The note-taking exercise was embedded in one of the field lessons in a week-long module on geothermal geology techniques. Primary learning goals are listed in Table 1 (Refer to Table 3.1), with the second learning goal the object of this study. The note-taking exercise encompassed the first hour of the field day and was integral to the day's activities as well as for the entire module. The class size (~45 students) necessitated splitting into two groups for the lesson. Two different lecturers led the class on either day. Both lecturers have discipline specific expertise in this area. A graduate student tutor also assisted the lecturers, to illustrate geothermal analytical procedures (which were not the focus of the lesson on both days).

Table 3.1: Primary Learning Goals for Note-taking Lesson

After participating in the field note-taking activity, the students will be able to...	
Goal 1	*Locate* themselves on a map, recording the relevant location information
Goal 2	*Make* and *record* visual observations at a geothermal hot spring.
Goal 3	*Draw* and *annotate* sketches in order to *illustrate* the overall and detailed features of the geothermal hot spring
Goal 4	Take *measurements* as a group (e.g., Conductivity of the waters) at a geothermal hot spring
Goal 5	Perform goals 1-4 in order to fully *characterize* a hot spring, recording it into their geologic notebooks.

The lesson followed our working definition of geoscience best practices and had the following design characteristics:

1. Prepatory activities, such as an introduction to the geologic context and geographic area and the general field environment, were done prior to the exercise (in the week leading up to and the day before) to reduce novelty space effects.
2. The field exercise was built upon the central themes of geothermal geology in order to encourage development of appropriate schema (Bransford, Brown and Cocking 2004).
3. Lecturers were asked to present manageable tasks (Chandler and Sweller 1991; Pollock, Chandler and Sweller 2002) in a learning-goals-focused, organized workload to reduce cognitive load (Chandler and Sweller 1991; van Merriënboer and Sweller 2005).
4. Lecturers used the Socratic method (Overholser 1993a; Overholser 1993b) and encouraged peer interaction and support.
5. Students were introduced informally to field 'best practices' taken from Compton (1985) (above) in several ways: a) comparing their notes to expert notes; b) practicing a top-down in-field strategy (large scale to the small scale; (Vick, Boardman and Henrickson 1979) in the week prior; and c) emphasising separating observations from interpretations.
6. Students were encouraged to use their own words and to not concern themselves with geologic jargon (to avoid the 'show and tell' effect (Haigh and Gold 1993) of more traditional field trips).

3.3.3 Coding Student Notebooks

Every item or 'phrase' within the class dialogues and the students' notebooks was coded and assigned to specific categories utilising ATLAS.ti coding software. The first pass was predominantly concerned with content guided by the primary learning goals for the lesson (see Table 3.1). Lecturers presented additional material that was not specified in the primary learning goals. These secondary learning goals were identified and coded within the class dialogue and the students notebooks. These were used in this study to understand what the lecturers set out to do, what they actually did, and what information the students preferred to record.

The second pass of coding separated out each phrase and assigned them into *unique* or *verbatim* (i.e., 'parroting' phrases exactly from the class dialogue) categories. Below is an example from the lesson dialogue, describing a geothermal feature called *sinter*, to illustrate *verbatim* content.

Lecturer 1: ... how would you describe it [points to sinter rock texture directly in front of the students]?
student response A: it's white
Lecturer 1: It's *white*. And what else would you say about that? Over there. [doesn't point]. What's the texture of it?
student response B: it's chalky
Lecturer 1: It's *chalky*, Ok. So it's white and chalky. What else? Any other textural words you can come up with to describe just on the other side [gestures, flattens his hands and points to sinter terrace] this white stuff?
student response C: it's *cracked*
Lecturer 1: Yea, it looks like it has little cracks in it. Really simple word maybe to describe it...?
student response D: it's a rock
student response A: laminated
Lecturer 1: Yea it's a rock, it's laminated. But then even more simply. You're always good with these, [student name]? A word that describes this really, cracky, laminated stuff... [pause for approximately 6 seconds]
student response E: scaly
Lecturer 1: *scaly*. Exactly, that's the word that I was thinking of. Ok, so it's looks really scaly.
(Transcript from video observations of Lesson Dialogue with Lecturer 1 and students)

Students in this particular category recorded nearly *verbatim* what the class had discussed recording the descriptive words that are indicated above: white, chalky, cracked and scaly. An example of a student's observation with these textural terms: "... other side [of the terrace] is white, chalky, cracked and scaly" (Class 1 student, notebook transcript). This student used all *verbatim* terms when describing the sinter texture despite students having been asked to make their own observations prior to the class dialogue.

3.3.4 Uniqueness and Completeness Metrics

Using the coded lesson dialogues (which contained all phrases and observations used in the lesson) and the students' notebooks, we defined two measures, which we call *uniqueness* and *completeness*, to understand the behavioural abilities of students' note-taking experience.

For each individual student, *uniqueness* is defined as $\frac{n\ of\ unique\ observations\ made}{total\ observations\ made\ by\ student} = \frac{U}{U+V}$

A high uniqueness ratio signifies that the student has a higher proportion of original phrases. Unique phrases (U) include and can be broken down further into two categories: Paraphrased phrases; and *extra* phrases (E). For example, Sally included 25 unique observation phrases (including 5 extra phrases) and 25 verbatim phrases. Her uniqueness value would be 50%. This means that 50 percent of the observations that she wrote down were unique (either paraphrased, or extra to what the class had discussed).

For each student, completeness is defined as $\frac{n\ of\ observations\ made - n\ of\ extra\ obvs}{n\ of\ class\ observations} = \frac{U+V-E}{T}$

Completeness (C) represents how many phrases the individual student has recorded, as compared to the Total observations made in the class lesson dialogue (T). In order to isolate how closely the student's note-taking matches to the class dialogue, we will omit extra observations (E) from the total unique observations (U) because those phrases represent additional information rather than being part of the lesson's discussion. For example, Sally's notes showed 30 unique observations, 5 extra observations and 50 verbatim observations; while her class had a total of 100 observations. Sally's completeness would be 75%. This means she covered 75% in her own notes of what the class discussed but also included 5 extra phrases which the class had not discussed. Students who excel at completeness are likely more capable of transcribing information, but less so at processing it as noted in Ganske (1981). Students who excel at both completeness and uniqueness would theoretically be sound processors and transcribers.

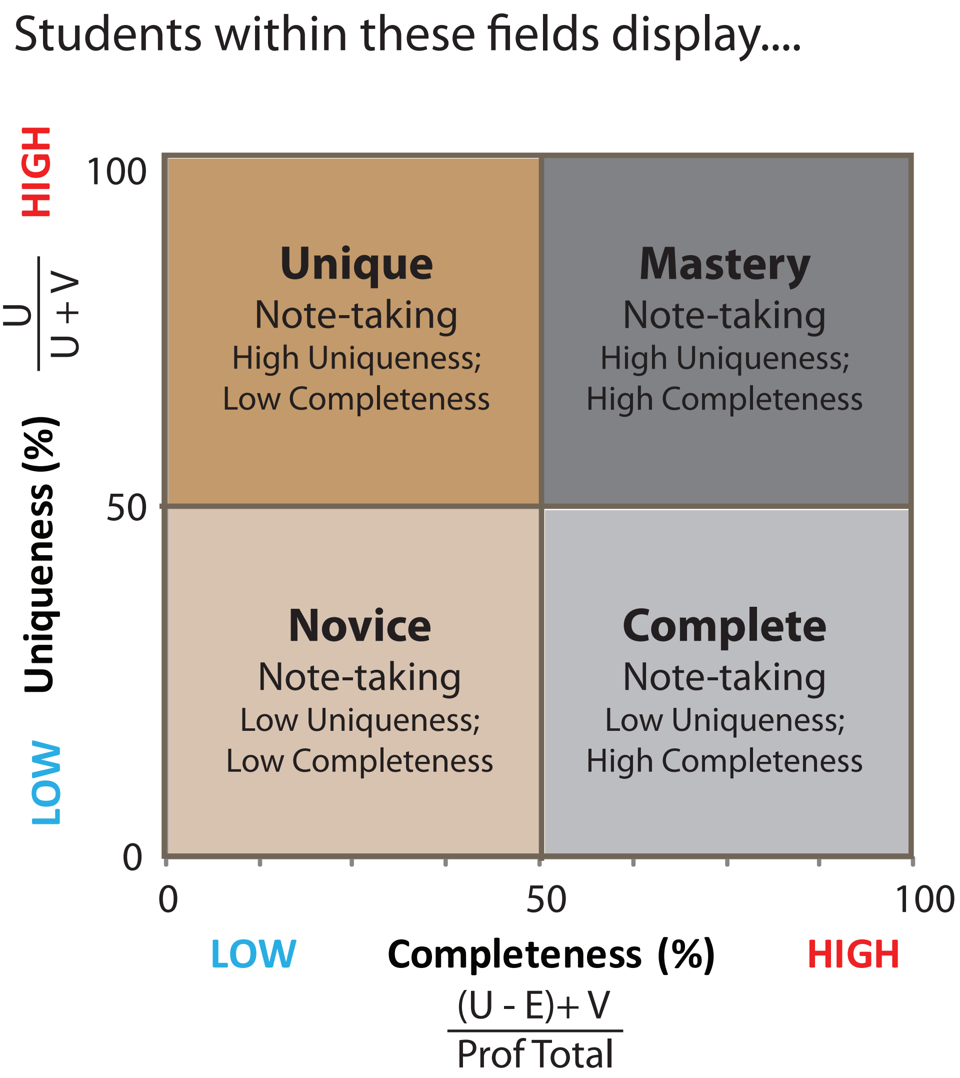
Efficiency is another semi-quantifiable 'best practice' that is often perceived as an asset to have in the field particularly in applied or industrial settings. Efficiency is calculated by taking the Total phrases observed by the student and divide by the number of words used (Williams and Eggert 2002); e.g., Sally's notes showed 50 observations total and she used 100 words to describe those observations. Sally's efficiency would be 50%. Efficiency was not an explicit goal of the note-taking activity, although it was mentioned in the best practices, which were set out to the students prior to and during the activity.

The last parameter explored was the proportion of primary (refer to Table 3.1) to secondary learning goals. The proportion of primary goal content compared with the secondary goal content was used in order to assess a student's preference for including these two different types of information. For example, Sally recorded 40 observations about hot springs (primary learning goals) and 10 statements which were interpretations or contextual information provided by the lecturer. The proportion of primary learning content recorded (over the total content recorded) was 80%.

3.3.4.1 The Note-taking Ability Diagram

A plot of uniqueness versus completeness can be used to characterize different levels, or abilities of note-taking. The students' results are broken into four quadrants of behaviour: *Unique-type*, *Mastery*, *Novice* and *Complete-type* note-takers. This diagram will be used in many plots provided in the Results section of this paper to help differentiate the possible factors and influences that may affect the student's success with the note-taking activity (Figure 3.2).

Figure 3.2: A plot of completeness (in %) versus uniqueness (in %). Students are broken into quadrants which show Unique-type, Mastery, Novice, and Complete-type note-taking behaviour. We have defined here that Mastery students are those who display high completeness and high uniqueness. Novice note-takers illustrate the opposite. Students who excel at uniqueness (writing down predominantly independently-derived content) are Unique note-takers; while Complete-type are students are dominantly focused on and essentially writing down what was said in the lesson, verbatim.



3.3.5 Student Interviews

Interviews with 16 students in a focus group format were conducted five months after the note-taking exercise. Focus group sizes ranged from pairs, up to four students per session. The interviews ascertained student perceptions about the note-taking activity and field note-taking strategies in general. The 16 participants (9 female, 7 male) interviewed represented the range of note-taking abilities and geologic experience.

Interview questions aimed to uncover what strategies (if any) students employed in the field. We were primarily interested in their perceptions of the level of difficulty of note-taking and specific factors they perceived to affect their ability to take notes. The questions included:

> Researcher: Think back to the day that we visited [the field site]. That day we had you fill out a paper notebook, which we called the note-taking activity.
>
> a. Do you remember that day? What was the most *memorable* part of that day in the field? Why?
> b. Did you feel *challenged* by the note-taking activity? Why?
> c. What do you think you've *learned* from that note-taking activity? Why?
> d. What is the *best setting* to learn note-taking and/or observations skills? Why?
> e. In hindsight, would you have taken notes *differently* or changed your behaviour (based on what you know now)? Why?

3.4 RESULTS

Two types of data were analysed for the purpose of understanding note-taking behaviour: 1) the semi-quantitative results derived from the text of the students' notebooks; and 2) summarized and detailed excerpts from student interviews. The plots of uniqueness versus completeness in these sections are plotted herein. The lines or boundaries between these field on the plots (between the quadrants) are arbitrarily chosen (50% mark) for both axes for our student population. We have also plotted mean values for the student population, to illustrate that this alternative boundary line may be helpful in showing "above" and "below average" behaviour. Further research with a larger range of geologic expertise should help us to define these boundaries more meaningfully and accurately.

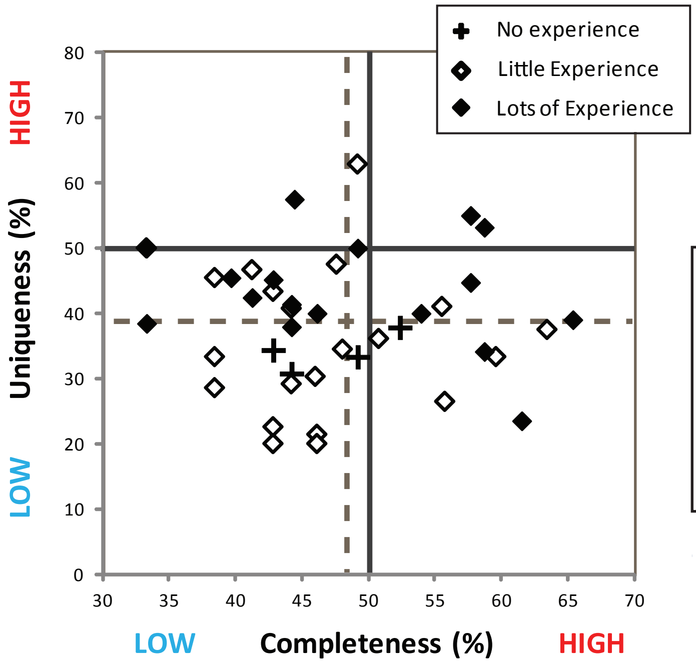
The following subsections report the results from these data grouped by the research questions of the study. The research questions characterize how the following variables impact students' note-taking experiences: 1. previous geoscience field and coursework experience (Section 3.4.1) and 2. Perceptions held by the students (Section 3.4.2). Additional findings are presented herein: gender differences (Section 3.4.3) and lecturer teaching style (Section 3.4.4).

3.4.1 Previous Geoscience Field and Coursework Experience

Figure 3.3 represents a plot of the students' results when 'sorted' by general field experience and independent research experience. Figure 3.3A shows that students with 'lots of experience' (as defined earlier) achieved higher uniqueness results (Figure 3.3B: a statistically higher mean, $p=.02$ was derived through an independent t-test for two different means) and therefore, trending more towards Unique and Mastery classifications. The uniqueness values for the entire population on average were 39% while completeness values averaged around 47.5%. Statistically, students with different backgrounds in field experience do not have different completeness values. Figure 3.3C illustrates that all the students who have independent research experience (9 of the 42 students) have above average uniqueness and trend towards the Unique and Mastery classifications as well. These findings are in agreement from research by Barnett and Freud (1985), which found that students with previous experience will more commonly record *unique* information.

Figure 3.3: A Note-taking Ability plot filtered by the amount of the student's previous field experience. Solid lines represent the 50% threshold, and the dashed lines represent the averages of each variable for the whole student population. A. Students with 'lots' of previous field experience are plotting closer to, and within the Unique, and Mastery fields. B. Basic statistics of the different populations of 'No', 'Little', and 'Lots' categories. Students with lots of experience achieved statistically higher uniqueness values. C. All the students who had independent research experience were shown to generally have higher uniqueness than those who did not.

A. General Field Experience

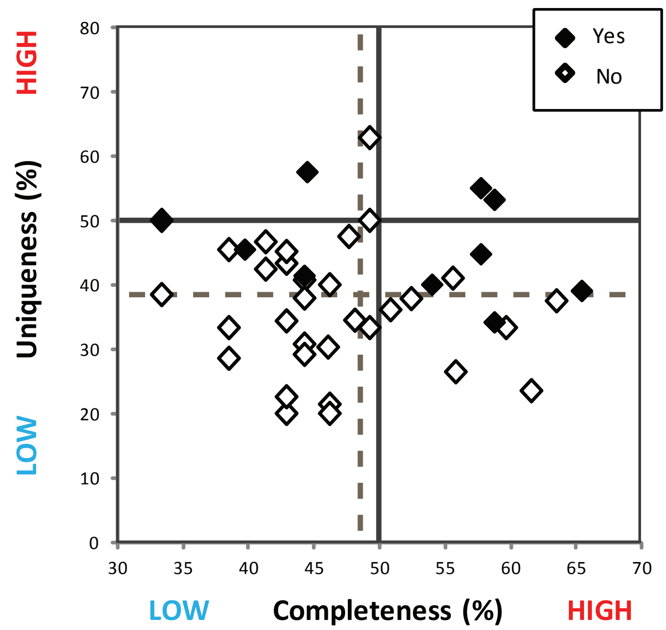


B.

Basic Statistics - Uniqueness

	None	Little	Lots
n	4	21	17
mean	34	35.8	43.4
s.d.	2.93	11.18	8.32
p-value (different means)		**0.02**	

C. Independent Field Experience



Focus group data revealed that there were mixed student perceptions on whether previous geologic experience reduced the task difficulty. Several students indicated that previous field experience positively affected their note-taking abilities. They felt that they needed an adequate "background" before going into the field and needed to know "what to look for" in order to reduce the difficulty. One student remarked: "Yea, I definitely think that you need a background before you go out into the field. You need to know what you are doing. And what you are looking for. That's what I found for the [another field assignment] one. I struggled so hard with that" (Interview transcript, Complete-type student 1). Other students were unsure of whether it lessened the difficulty: One student summarized a common theme: "... [the note-taking activity] was kind of difficult... even after our 5-week field course, I am still not comfortable taking notes" (Interview transcript, Unique-type student 1). Aside from experience, encountering the 'new geologic scenario' contributed to the difficulty of the task: "It was a little bit challenging in that it was really different from other stuff we have been doing. It was geothermal instead of sedimentary or metamorphic or whatever..." (Interview transcript Novice-type student 2)

Whether the students had 'a lot', 'little' or 'no' previous geoscience coursework was also explored as a possible factor that influenced students' abilities to take notes. The student population was generally made up of geology majors (n = 26), with fewer environmental sciences (n = 8), engineering students (n = 8). An environmental sciences student, with little geology coursework, but 'lots' of field experience scored within the Mastery category. We sorted the students by the number of geology courses but we did not see a clear effect (i.e., noticeable clustering on the Note-taking ability plots, or statistically significant difference in means) from coursework on the students' note-taking abilities. Some students with very little geologic background still scored higher uniqueness and completeness values than students with substantial geologic coursework background. Additionally, the six participants who had been introduced to geothermal concepts in a previous hydrogeology course showed a range of uniqueness and completeness values.

3.4.2 Student Perceptions of Note-taking and the Field Environment

3.4.2.1 Note-taking Strategies

The majority of students interviewed (12 of 16) admitted that their primary strategy was to ‘write everything down’. For example: “I feel like it’s easier to just write down everything and anything. Because you think, ‘I don’t know when I will be back here’, so you just try and get down as much as you can. Yea, just write down everything” (Interview transcript Novice-type student 3). Despite this strategy, this student scored one of the lowest completeness values of the study population. Another Novice note-taker reported: “Yea, I was basically just writing down everything, because we were getting so much information thrown at us, at the time. And like, I didn’t know what was important. So then, I was just writing it all down” (Interview transcript Novice-type student 1).

While a Mastery note-taking student describes a different experience:

Researcher: What do you feel that you learned from the note-taking activity?
Mastery 1: I think just the reiteration that you have to write [emphasis] things [emphasis] down [emphasis]... It makes you deal with it. So you have to think ‘this is the larger perspective’ and ‘this is the small perspective’ and you have to really think. You can’t just say ‘there’s orange stuff here’. Like there is orange stuff here, but it could be ‘this’, or ‘this’ and it’s a process. It makes you reason more, or process the ideas more in your head. Otherwise you might just skip over things and write your picture and then you look in your picture and think ‘I can’t skip that part, because it’s in the picture’.
[Interview transcript, Mastery 1]

This student describes the detailed processes that one must take to characterize geologic features, as well as a common expert strategy of going from a ‘larger perspective’ to a smaller one (Vick, Boardman and Henrickson 1979). Many students also described having a ‘top-down’ or ‘big-picture to 'small-picture' strategy to observations: "I tried to have a strategy and record the broad stuff and then work my way down to the macro-, the meso-, micro scale stuff" (Interview transcript, Unique-type student 1). Several students noted that a primary goal of note-taking is so that it can 'easily be read' by another geologist. One student noted: "And I've heard that you should always try and write your notes, so that another geologist can see what you are saying" (Interview transcript, Independent-type student 1). This implies a use of note-taking language and approach that are intelligible by other geologists.

One of the Novice-type students explained why making observations in the field is so important. This anecdote [he/she] recalls is from one of [his/ her] first field experiences earlier in [his/her] degree programme:

Researcher: What setting or style of learning, can observations best be taught? In the field? In the lab? In the classroom?

Novice 2: I think being out in the field [is the best], like my first year in college and we went out for a lab for whatever reason. It was like: 'Ok, get out there, take some strikes and dips and measure everything'... So [the lecturer] didn't really say anything, [the lecturer] just let us take our measurements, write everything down. And then we got back and [the lecturer] was like: 'Write a lab report on what you did and why it's important'. And we were all like: 'Shit, we don't have any information' [laughs] and then like 'Why didn't we take this?'. And [the lecturer] was sort of laughing at us. And said 'Ok, now you guys learn from your mistakes. We will have another field trip next week so that you can go back out to collect data'. And I think that is so much of what it is. Knowing what you need to get from the field. Not because someone tells you what to do – or because it's in a book. But because you go out and you realize... like you need to have it down on paper or somehow documented.
[Interview transcript, Novice 2]

This student describes powerful understanding of the reasons why one takes notes and what they need to do to achieve high performance in note-taking. However, despite these insights the student plotted within the Novice-type category. Regardless of the knowledge and understanding of the field note-taking, this student has a clear awareness of what they should be doing during a task – yet fails to meet their own and other's standards.

3.4.2.2 Factors that Affect Note-taking

Several students mentioned that the people or *social* environment was a distraction or impedance to their learning in the field environment. One Novice student stated the strong desire to explore, rather than focus on the task at hand: "I wanted to let the little twelve-year-old inside of me just like, run around and look at everything and touch stuff and take pictures" (Interview transcript Novice-type student 2). In addition, human social interactions were a distracting factor, with several students commenting on their pre-occupation with flirting with other students, rather than focusing on the task at hand.

Several students mentioned 'the level of detail' as an intrinsically difficult aspect of making observations and note-taking in the field. Some students said they felt they got into "too much detail": "... there's other times when I don't know, I feel like I am getting too detailed, like unnecessarily so in field areas (Interview transcript, Unique-type student1). "There are huge differences in the level of detail you can see... You see a lot of subtle features out in the field, compared with [other learning activities]. Sometimes seeing all those little subtleties makes it more confusing and sometimes it helps you out to understand things a little better" (Interview transcript, Novice-type student 1). This level of detail describes how Novelty Space affects the overall cognitive load of the exercise.

3.4.2.3 Note-taking Improvements

There are several themes that emerged from the interview data which describe strategies that students suggested might improve their note-taking:

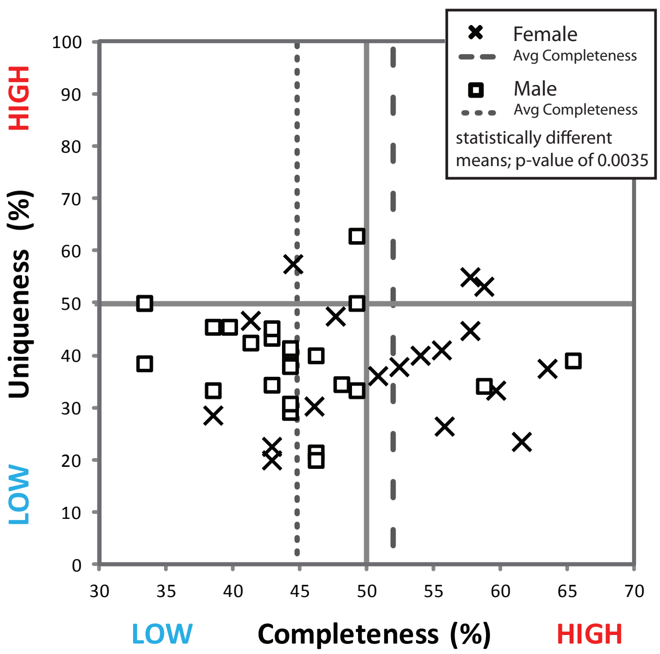
1) Having a ‘cheat sheet’ of important geologic observations prior to the field experience: “I really actually wish that I had a list [of geothermal observations] to bring with me, afterwards. So like if I found myself in a geothermal area again, I would have like a list of questions like that.” (Unique-type 1, Interview transcript)
2) Using technology in the field to improve the quality of their notes: “I would ask for an iPad or something [student laughs]. Because I hate [emphasis on the word ‘hate’] doing it by hand. But if I had a mini-computer and then I could break it up into sections: data, observations, interpretations. It would be more organized, segmented... But I think definitely like structuring it, right in the field. That would help me so much more! (Novice 2, Interview transcript)
3) Improving organization and structure of their notes: “I would probably organize it a little better. Like I would pick some [geothermal] pools and then organize, rather than one huge long rant. I think like the same ‘volume’ of words, but just better organized” (Complete-type 2, Interview Transcript)

3.4.3 Gender Influences

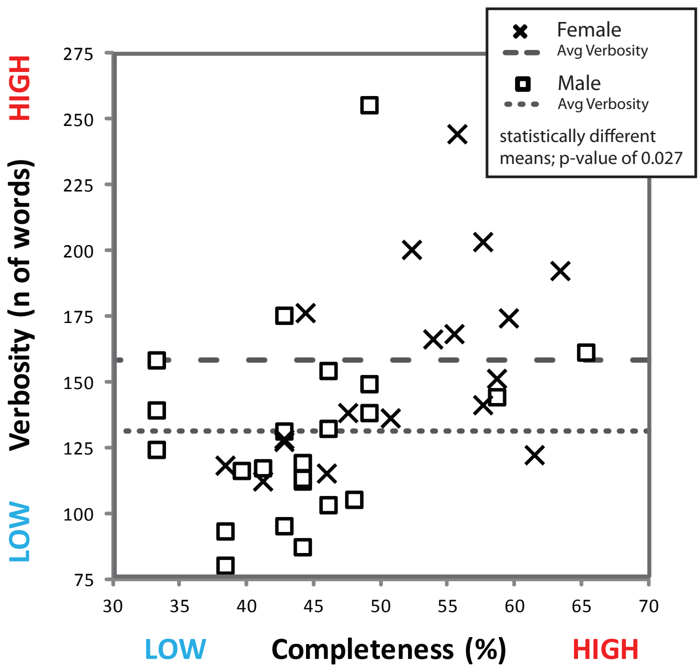
Initial passes during coding showed us that generally female students wrote more than male students, leading us to hypothesise a relation between gender and verbosity and gender and completeness. Figure 3.4A illustrates that on average completeness values for women (52 percent) was higher than men (44 percent). Plotting verbosity versus completeness (Figure 3.4B) shows that generally female students wrote more (average of 157 words compared to 130 words for males) and this strategy led to a higher completeness metric. The mean completeness and mean verbosity for the different genders are statistically different ($p= .0036$ and $p=.027$, respectively, using an independent t-test for different means) while there is no statistically significant association between gender and uniqueness.

Figure 3.4: A. The Note-taking ability diagram sorted by gender. The dashed lines represent the average of completeness values (all students, solid line) for men (dotted line) and women (dashed line). The Mastery students were both women, and more men generally fall within the Novice category. B. Verbosity plotted against completeness plot illustrates that females used more words on average than male students.

A. Gender Differences



B. Verbosity



3.4.4 Lecturer Teaching Style and Pedagogy

We explored sorting the students by Lecturer 1 or Lecturer 2. The two lecturers covered very similar content and tasks but had different teaching approaches, as revealed by the lesson transcripts. Lecturer 1 included more additional, contextual information to what the students were doing (e.g., processes, interpretations, etc.) than Lecturer 2. An example of this is illustrated by an excerpt where Lecturer 1 describes how a hydrothermal eruption occurs, which is relevant to the formation of the hot spring.

Lecturer 1: So you are dissolving the rock beneath [referring to the hot spring] and stuff just caves in [makes a 'funnelling' gesture with his/her hands]. Or you can have an explosion maybe [gesturing upwards, cone] in a really vigorous geyser event that it is so powerful that it actually rips out the rocks. For the geologists, we have talked about these before. What types of explosions are those?
Student response: Phreatic?
Lecturer 1: Yea, phreatic explosions. Phreatic is a fancy word for water. So if you build up enough pressure and you decompress that and you release that pressure rapidly, you can cause a rapid phase change – from water to steam, that expands – and can trigger one of these phreatic eruptions. [Class 1 Dialogue, Video Transcript]

This information is quite peripheral to the primary learning goal (recording observations at a hot spring) but provides rich, contextual information about the larger geologic processes that give rise to geothermal hot springs.

In contrast, Lecturer 2 provided much more procedural instructions and best practices at the field location. Lecturer 2 stated the primary learning goal to the students, several times. For example: "So now the important part of the task, or the bit that we are here for, is to learn how to describe the features in front of you, OK?"; and "Ok so we just want to be sticking to our observations." [Lecturer 2, video transcript]. More importantly, the lecturer also encouraged students to think and write independently and explained why note-taking is important:

Lecturer 2: Yea, nice, a [hot] spring. A [hot] spring or a 'leaky pool'. It's actually fine to use normal words in your notes. You don't always have to use a fancy geology word. You are just describing in whatever the best way possible. If it's easier for you to describe it as 'a leaky pool', then describe it as a 'leaky pool'

…

Lecturer 2: Ok, so do people agree [with student A]? So don't just copy where [student A] has put it, because [he/she] might not be right. Where did you put it?"

…

Lecturer 2: So make sure you are thinking about this information and that you are not just writing this down.

...

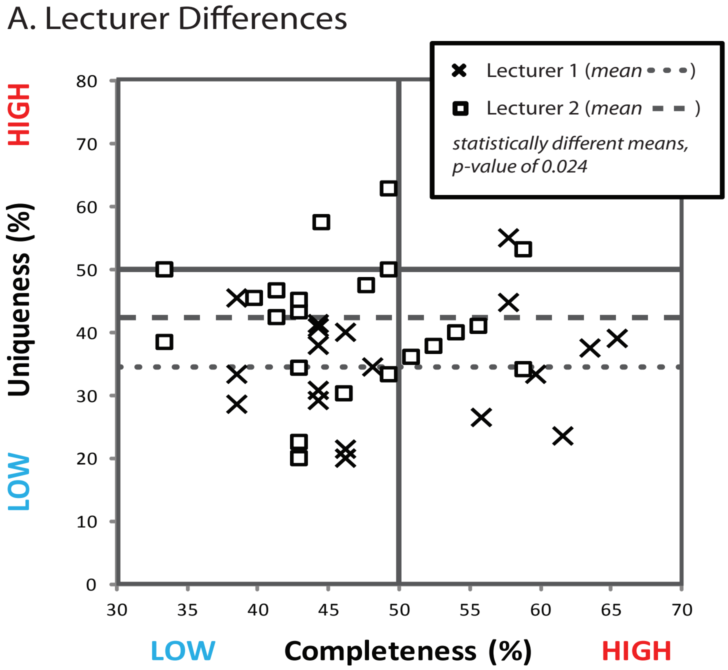
Lecturer 2: Ok, 'che ching' so it's not only good to write down the [observations] write something stupid down, that can help you remember. Just wanting to be thinking about ways to embed this into your brain. So that when you come back home and your notebook is covered in water and half rubbed out - at least some information is there that can help you relate to where you've taken your notes

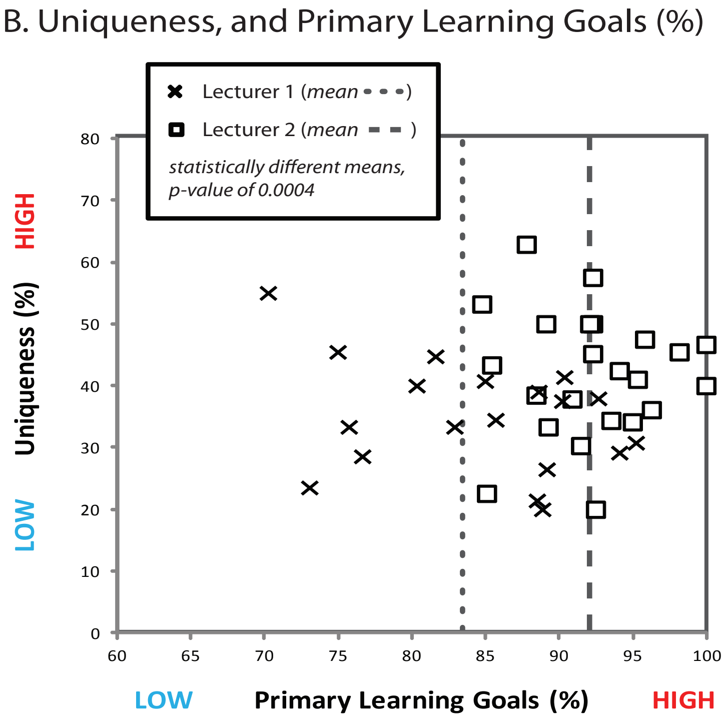
[Class dialogue, Lecturer 2 transcript]

Overall, Lecturer 2 explicitly impressed upon the students the importance of thinking and writing independently and using their own language while Lecturer 1 did not explicitly state the importance of writing 'in their own words'. Both lecturers systematically addressed each type of visual observation and commented on the relevance of that particular observation; but they did not declare that the primary goal was to 'write everything down'.

We suspected that less experienced students would have a much harder time 'filtering' through the highly contextualized dialogue of Lecturer 1 and we qualitatively observed that many of them included this 'extraneous' information in their notes. Figure 3.5A illustrates that the uniqueness values do differ (on average) between the different Lecturers ($p=.024$, using an independent t-test for statistically different means) but the completeness values are not different. Carrying on from that, we plotted up the student's uniqueness ratio against the proportion of recorded phrases related to the primary learning goals (i.e., only observations, location and measurement goals; Figure 3.5B). We see that students in Lesson 1 (with Lecturer 1) included some of the lowest uniqueness values which we attribute to inclusion of *extraneous* information (low percentage of primary learning goals) provided by the Lecturer.

Figure 3.5: A. A Note-taking diagram sorted by lecturer. Students taught by Lecturer 2 achieved higher uniqueness (on average). B. A plot of uniqueness versus the proportion (in %) of primary learning goals (to total phrases). This plot illustrates that a significant portion of Lecturer 1's students had low primary goal % values corresponding to low uniqueness values.





3.5 DISCUSSION

The results of this study indicate that students' ability to take notes in a geothermal field setting is influenced by similar challenges, strategies and perceptions discussed by researchers of Novelty Space (Orion and Hofstein 1994; Orion 1993), cognitive load theory (Van Merriënboer and Sweller 2005) and note-taking literature (Van Meter, Yokoi and Pressley 1994; Bonner and Holliday 2006). The combined effect of a new geologic environment (with social and sensory distractions), introduction to a new geologic topic and executing note-taking strategies resulted in differential success: that some students coped well, while others showed evidence of experiencing cognitive overload. In this section, we discuss how the students' experiences, demographics and perceptions (given the original research questions) influence their note-taking strategies. A final subsection discusses possible suggestions for improvement that students reported within the interview data.

3.5.1 Factors and Strategies of Note-taking

In a field lesson, a student is required to encode and vet the information provided and combine it with their own observations of the geologic environment. We showed that students with 'low' geologic field experience are likely to become easily 'overloaded' during encoding and abandon making their own observations in favour of writing notes verbatim from the lesson. The interview data provided indirect evidence that cognitive load and novelty space issues affected the students' abilities to take notes. Students also mentioned the overall *distractive* environment that they encountered at the geothermal hot springs.

Previous geoscience experience (namely in independent field experience) contributed to the students' overall note-taking success (Figure 3.3), resulting in statistically higher uniqueness values and is likely derived from elementary note-taking schemata developed from previous field work. Having more field experience will also reduce the ‘unknowns’ when writing notes in the field environment which in turn reduces Novelty Space (Orion and Hofstein 1994; Orion 1993). We suggest here that increased field experience many also help geologists develop *transferable* note-taking strategies (can be successfully applied to many situations) and more positive self-efficacy.

Although previous field experience appears to have a strong relationship with note-taking, having previous geology coursework did not affect the students’ abilities. A commonly held misconception by geoscience instructors is that information is delivered (i.e., geothermal concepts), then a student ‘should be capable’ of performing field tasks related to these concepts by independently building upon their previous field work experiences. Current research in the area of skills and situated learning implies that successful performance of domain-specific skills should be taught in an embedded, authentic curricula (i.e., information must be embedded in the situation in which it is used for effective recall and performance, in this case in a field environment, not a classroom environment) (Schon 1983; Roth and Roychoudhury 1993).

Complete-type note-takers exhibit a success for completeness, but achieved low uniqueness values. Van Meter et al. (1994) research suggests that students will adjust their note-taking strategies to the perceived level of difficulty of the task. Inexperienced students considered the note-taking exercise as a ‘difficult’ task and therefore likely resorted to ‘parroting’ or ‘mimicking’ as a means of coping with the large amount of information provided. This strategy proved effective as the parroting students showed high levels of completeness. We suspect that this strategy may be derived from the traditional classroom and examination environment, where complete, comprehensive answers will elicit higher grades than unique responses. The fact that the women in this study wrote more (higher verbosity) is connected to the completeness values (Figure 3.4) achieved. By the classification of Ganske (1981), women fit into Category II note-takers (high completeness, organized, more easily read), however there is not sufficient information in this study to fully understand gender differences with note-taking. We speculate that these results are related to similar findings in the literature to suggest that women are outperforming men (measured primarily by GPA) due to their stronger academic ethic (e.g., Chee, Pino and Smith 2005) or more positive attitudes and note-taking self-efficacy (Carrier, Williams and Dalgaard 1988), but our data does not allow us to draw firm conclusions in this regard.

The majority of male students (20 of 24) scored within the Novice-type Category, but were trending towards the Unique-type note-taking quadrant. However, the note-taking categories that were defined in this study (as depicted in Figure 3.2) are arbitrary, based on cut-offs at the 50 percent mark and require further research. Some of the male students paraphrased and included many additional or 'extra' observations. It is possible that men are more focused on writing in their own language and much less concerned with getting all the information, but rather, the 'right' or 'important' information. This could be derived from generally higher levels of academic self-efficacy (i.e., critical thinking skills) reported in tertiary-level men, compared with women (Lundeberg, Fox and Puncochar 1994; Beyer and Bowden 1997; Jordan, Libarkin and Clark 2009).

It is also possible that Unique note-taking students focused their energy on writing notes in their own words, or they simply valued this best practice *over* completeness. Van Meter et al. (1994) reports that students who paraphrased the lecturer's content did so, in order to "increase [their] understanding of class content". Therefore their note-taking strategy could be an attempt to comprehend, or learn more. Additionally, researchers have shown that some students will miss main points during classroom note-taking, because they focus too much on the minute details rather than the main points (Williams and Eggert 2002). Both Complete-type and Unique-type students may transfer their classroom note-taking strategies in order to achieve different goals (i.e., Complete-type may be aiming to get ‘everything down’; while Unique-types seek to record information on their own terms).

Student interviews (excerpts from Novice 1, Novice 3, and Section 3.4.1) and analysis of Novices notebooks (Figure 3.3) show that these students had a less success (based on our metrics) in the note-taking task. When confronted with difficult tasks, researchers have found that geoscience students can choose to use superficial learning methods (Prothero 2000). We suggest here that low completeness is due to students ‘missing information’, while low uniqueness is due to poor or abandoned attempts to ‘filter’ the information provided. Both of these failures are a result of the distracting environment, high cognitive load and failure to employ successful strategies.

Field trips are acknowledged to positively influence the affective domain outside of the cognitive learning sphere (Kern and Carpenter 1984; Boyle et al. 2007), however, social dynamics can be a powerful motivator or distracter, particularly if not acknowledged by the lecturer and students. Staying on task can be difficult in these novel environments. One student’s perceptions of ways to overcome the distractions of this complex, challenging environment is stated below:

Researcher**:** Where you do think the best place to learn observations? Where is the best place to learn these? In the field? In a videogame? In a lab? In a lecture?

Student: I’m not even sure it matters where you are, as much as it’s the state of mind that you are in. As long as you are not distracted by things, by other people. So that you can just observe. You are observing. Like, there were a couple days in field camp where I probably did not observe anything, because I was just talking to people and ya know, like off in my own little world. I definitely observed the most when the professor was like ‘Ok, no one is allowed to talk. You sit over there, you sit over there and you all draw and you think and you just write things down' [Undifferentiated student [did not hand in their notebook], interview transcript]

The lecturers' slightly different pedagogy employed during the exercise was shown to affect the students' cognitive load and thus the content of the information recorded (Figure 4.5). Cognitive load is increased by including non-task information while students are performing a task (Chandler and Sweller 1991; van Merriënboer and Sweller 2005) and that providing instructive (or procedural) information during a task can indeed decrease cognitive load (Kester et al. 2001; Pollock, Chandler and Sweller 2002). The combined effects of these slight pedagogical differences resulted in an overall higher cognitive load in Lecturer 1's class, particularly for Novice students (in this case, students with not as much field experience). Interestingly, the styles did not seem to alter the proportion of students within the given (or direct students into) different note-taking ability categories. Alternatively, differences may occur due to a lack of explicit instructions on note-taking best practices. The lecturers were not prompted prior to the experiment, to explicitly state these best practices – as the purpose of the study was to replicate a common field teaching lesson. Therefore, it is possible that if the lecturers had both explicitly stated the importance of both completeness and uniqueness then the results of this study may be different.

3.5.2 Suggestions and Implications for Note-taking Pedagogy

There were several suggestions made by the student participants for methods to help students maintain focus and complete their task successfully. Several students indicated that having an introduction to the set of criteria and list of observations that one should make would significantly help them to perform in a new geologic scenario. It seems likely that this suggestion would increase completeness, but its impact on uniqueness (and thus, independent thinking) is less apparent. Cognitive load theory indicates that student's cognitive functions will be assisted most by having procedural instructions given to them *during* the tasks (Kester et al. 2001). This allows them to work alongside their 'recipe'. However, giving students the list ahead of time makes the field lesson, less of an exploration (or inquiry-style) and may 'spoil the surprise' and subsequently decrease the students' motivation to learn. One of the Mastery-type students agreed, stating: "So [you have the list and] you go into the field and know what to write. But I'm not sure if that is a good thing. Ya know, *just* [emphasis] to have a list to *just* [emphasis] write everything down. But I guess those are the key observations and those are the ones to be writing down. So I guess it is a good thing." More research is needed to assess the effect of using a list of observations.

Preliminary research by Dohaney et al. (2012) may shed some light on the use of a list. A 3-dimensional, immersive videogame with the same content (observations) and similar digital field environment was used to teach students the basics of geothermal site characterization. A smartphone in the videogame provides 'the list' of things a student should look for in the field. Students recorded (in their own self-determined fashion) their observations using the smartphone list as a guide into a digital notebook. Notebooks were not coded, but preliminary interview data from this study indicated that students liked having a list and they referred to it during game play as a guide, but did not rely on the list.

To ensure efficient encoding of notes, handheld technology can be used in the field sciences to quickly record and organize information with students (e.g., Guertin, 2005; 2006; 2008) and professionals (Brodaric 2004; Clegg et al. 2006). Guertin (2006; 2008) discussed the positive effect that handheld technology had on students' attitudes, particularly with respect to data collection in the field. However, they also reported that students who are unfamiliar with certain technologies can be ‘put off’ by the additional task of learning technology while learning to write geologic notes and field map. Yet, there is also merit in training students to use equipment and software that companies use (e.g., ArcPad).

Besides basic best practices set out for lecturers in the field (presenting material at a reasonable pace and with explicit learning goals) during first instruction, lecturers may chose to separate out complex field learning tasks into more manageable parts. The following is a summary of our pedagogical suggestions arising from this study, the literature review, notebook analysis and interview data, but should be taken as preliminary as they need to be tested and researched further:

- Learning goals and note-taking best practices should be communicated clearly and reviewed as needed during the lesson in order to stay on task.
- Specific note-taking tasks can be broken into small parts (or modules) which are meaningful to experts in order to better manage and store information: Start with the larger perspective (the geologic region, the geographic features, the eco-biodiversity) then progress to the smaller perspective (the textures, minerals, colours of the features you are concerned with).
- Students should take a break between the parts, to *reflect* and *organize*, or re-organize their notes.
- Establish field ‘etiquette’, separating out ‘quiet time’ for observations and other times for task-specific peer interaction to reduce social distractions and to initiate and maintain focus.
- Once an introductory lesson has been completed, you can proceed to other geologic sites and allow students to take notes, in their *fullest complexity* in order to attain authentic field observations and note-taking. Emphasis in the later lessons should be on repeating and maintaining best practices.
- Practitioners should take any opportunity (written, or in person) to review students notes and make suggestions on how to improve. Feedback is crucial for the learning of any skill. If a student is not aware that they are not performing well, then they cannot improve.

3.6 CONCLUSIONS

Learning in the field can be a complex and overwhelming experience for most students. This study is a first step in characterizing field note-taking. By applying semi-quantitative coding methods to 42 student notebooks, we have illustrated that previous geoscience experience, gender and the lecturer’s teaching style can affect students’ note-taking experiences.

Results indicated that students with more geoscience field experience positively influenced students note-taking pushing students towards the Mastery category; while, previous geologic concept background (i.e., coursework) did not impact note-taking abilities. The majority of participants reported that they valued previous field experience when writing notes. However, some students achieved low scores despite a sophisticated understanding of what is required for good note-taking. We attributed these low scores to negative (i.e., distracting) social and environmental factors in the field environment.

Supplementary results indicated that lecturer’s pedagogy impacted the students’ note-taking. One of the lecturers included extraneous information which the students recorded in their notebooks significantly reducing the average completeness of the class. Gender also appeared to be a factor in note-taking. Female students had statistically significantly higher completeness values than males which were shown to be linked to writing more.

Our measures of uniqueness and completeness embody the qualities of a geology graduate, measuring their abilities to carry out independent thought and record all of the necessary information. However, these characteristics represent two different strategies that may be inherited from the student’s previous experiences, gender differences or the teaching style in the classroom or the field environment. Future research must explore and control for these variables.

This study analysed notebooks from one site location, in one sub-discipline of geosciences. As this is the first (to our knowledge) study of note-taking in a geological field environment, we concluded it would be best to begin with an isolated note-taking experience. Future studies will analyze changes in students field note-taking over a longer duration (e.g., longitudinally, i.e., looking at a population of students note-taking over an academic year or longer; c.f., Bonner and Holliday, 2006).

The unique and complex field environment can produce high impacts from Novelty space and high cognitive load. New research questions have emerged from this study, which require the attention of the field sciences community. This study is a first step for more concrete longitudinal research questions. In order to fully characterise the link between note-taking performance (based on our classification), and the perceptions and strategies used by the students, a larger cohort of participants and more directed questions (i.e., questions which are derived from explicit research goals) are required.

CHAPTER 4: THE GEOTHERMAL WORLD VIDEOGAME: AN AUTHENTIC, IMMERSIVE VIDEOGAME USED TO TEACH OBSERVATION SKILLS NEEDED FOR EXPLORATION

PREFACE

"What a computer is to me is the most remarkable tool that we have ever come up with. It's the equivalent of a bicycle for our minds."

- ***Steve Jobs, film titled: "Memory & Imagination" 1990***

"I would trade all my technology for an afternoon with Socrates."

- ***Steve Jobs, Newsweek, 2001***

This chapter utilizes the ***Constructivist paradigm*** to teach geological field ***skills***. It builds on the ***observational skills*** from Chapter 2 and takes them from the laboratory environment of the ***lab*** and introduces the learning environment of the virtual world. This moves towards more innovative ***virtual*** (Chapter 4) and ***situated*** (Chapter 5) teaching and learning methods. In the coming years, educational technology will be inevitably incorporated into teaching field geology. With this in mind, we must go forward with a theoretical and practical understanding of how geoscientists think and work in the field in order to design ***technology*** that will meet and fit their needs.

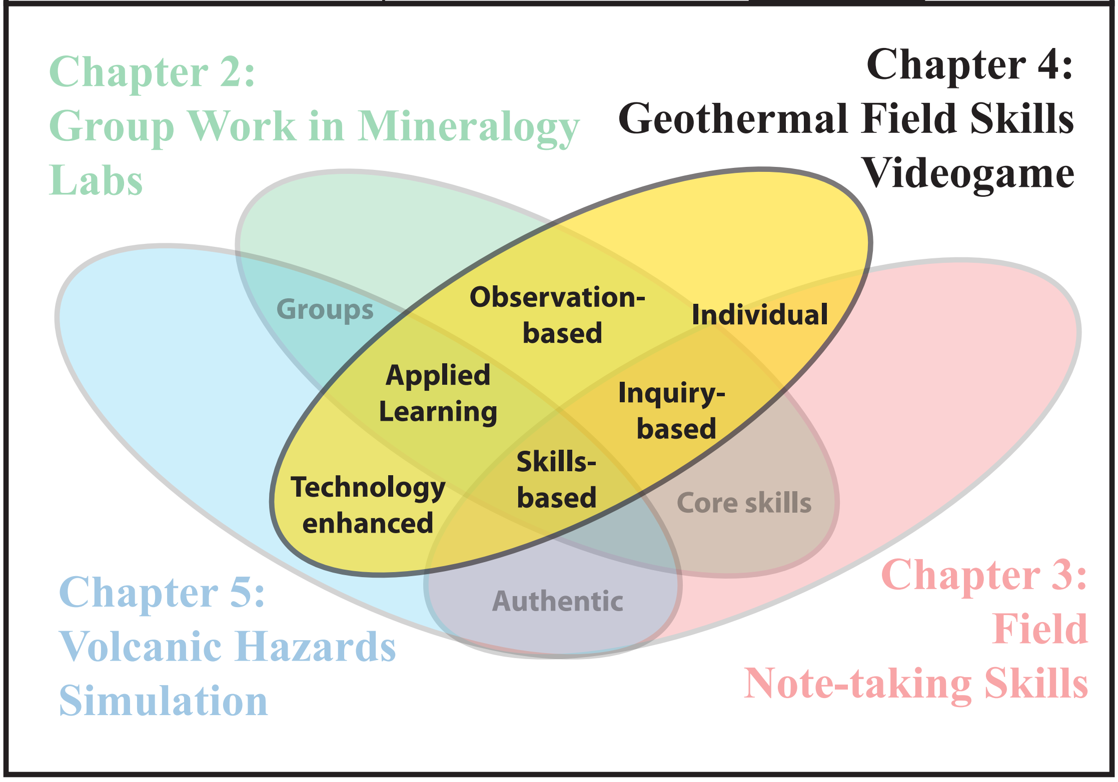
Chapter 2 focused on ***group*** learning, while Chapter 3 and 4 focused on the ***individual*** learner. Chapter 4 uses ***goals-based curriculum design*** to teach ***observation skills***. Although the primary use of observation skills may appear as a low-level Bloom's task, the synthesising and categorising of the observed information requires higher-level skills. The learning environment of the virtual world may not immediately register as an ***authentic*** learning experience; yet today's technology allows us to recreate an ***immersive*** experience which, in some aspects, is replicable to geology fieldwork. Fieldwork is not available to all learners for financial or access reasons, therefore these teaching tools are increasingly important for geoscience teaching.

Chapter 4 discusses the learning gains produced by a world-first three-dimensional computer videogame called 'GeoThermal World'. The design of the videogame incorporates ***inquiry-based, skills-based, scaffolding*** and ***supportive*** learning pedagogies within an ***educational technology*** design. These pedagogies are encompassed within self-determination theory (***motivation*** theories, e.g., Ryan and Deci 2000)and ***cognitive load*** theories (e.g., Chandler and Sweller 1991). Chapter 2 also utilised ***inquiry-based learning***, but here inquiry is driven by the ***technology*** for the ***individual*** student. The theories and learning strategies discussed in Chapter 4 are shown in Figure 4.1.

A version of this manuscript was awarded the NZGA (New Zealand Geothermal Association) best paper award in 'current innovations' at the Geothermal Workshop, where the proceedings were presented (See Appendix A6). The videogame aims to teach students the same skills that they might learn at a real geothermal field location. Further development of the videogame and educational technology like it, will grant us more insight into how these tools can be used to improve geoscience education.

Figure 4.1: Theoretical concepts (top) and learning strategies (bottom) which are discussed in Chapter 4.

	Chapter 2	Chapter 3	Chapter 4	Chapter 5
Goals-based Curriculum Design	✓	✓	✓	✓
Authentic Learning Environment		✓	✓	✓
Cognitive Load Theory	✓	✓	✓	✓
Novelty Space		✓	✓	



4.1 INTRODUCTION

"Fieldwork gives opportunities for learning which cannot be duplicated in the classroom. It greatly enhances students' understanding of geographical features and concepts and allows students to develop specific, as well as general skills" (Her Majesty's Inspectors 1993). Many geologists may think that field trips are the best (and possibly only) way to teach certain concepts and skills in geology but "… effective learning cannot be expected to follow just because we take students into the field" (Lonergan and Andresen 1988). Field trips have been shown to offer many valuable opportunities to learn theoretical concepts taught within the geosciences (e.g., Kern and Carpenter 1986; Elkins and Elkins 2007), however there is a paucity of rigorous education research on practical skill development (such as observations, taking measurements and note-taking), particularly in higher education.

Skills are thought to be acquired best through participation (active learning), hence activities are needed through which skills can be learned and practiced in the field setting (Lonergan and Andresen 1988). Observing, measuring and recording data from outcrops and natural phenomena are regarded as part of the primary skills that a field geologist should have (noted among other commonly taught field skills in Nicholas 2000). A main educational research question then becomes: How can we effectively teach field-based geology skills? Can we utilize videogames to achieve the same learning outcomes?

In recent years, virtual environments have emerged as a popular means of teaching geology and other science disciplines. There are different forms of technology (or media) that have been developed to supplement or even replace field trips and have been, thus far, aimed at secondary and introductory levels of the geosciences. These include: virtual laboratories (Clary and

Wandersee 2010), virtual or simulated field trips (Browne 2005; Benson 2010) and two-dimensional videogames (Schwert, Slator and Saini-Eidukat 1999). ‘GeoThermal World’ is the one of the first 3D, fully immersive videogames designed to teach upper-level students authentic geological skills.

Videogames can enable learners to see and interact with natural geologic phenomena that may be difficult or expensive to access. Interactive technology (like videogames) can present learners with explicit challenges, that provide instant, individualized feedback customized to the needs of each student (Honey and Hilton 2011). This level of one-on-one feedback is difficult to replicate in real life with students in the field.

Aside from general skills, geothermal geology is not typically required or the main focus of current curricula within undergraduate programmes in New Zealand. Exposing students to academic and applied geothermal topics, as well as possible career options for geothermal geologists (a growth industry in New Zealand) is a secondary aim of this project.

Figure 4.2: (Top) A photograph of the Hochstetter Pool (foreground) at Orakei Korako, which the students were asked to describe in the field (Photo taken by Daniel Hill). (Bottom) A screenshot of one of the three, fictitious Sapphire Pools that were described by the students in GeoThermal World videogame.

We discuss here the learning gains (i.e., knowledge acquired) achieved from a virtual field locality (the Sapphire Pools) within the videogame, compared to an actual field locality (the Hochstetter Pool) at Orakei Korako. Images of both settings are included in Figure 4.2.

Overall, we aimed to help students develop and apply a systematic and conscientious approach to geothermal geology and exploration. Both activities were designed with the same task-specific learning goals, which include transferable skills (i.e., skills that can be applied to any geologic field or scientific activity):

After participating in the videogame or field trip activity, students will be able to:

1. Make and record visual observations at a geothermal hot spring.
2. Know how to take quantitative measurements (e.g., conductivity) at a geothermal hot spring.
3. Perform goals 1and 2 in order to fully characterize a geothermal hot spring in a geologic notebook.

The following section describes the methods used in a comparative experiment designed to measure the knowledge acquired (i.e., learning gains) from both activities.

4.2 METHODS

Educational researchers utilise quantitative and qualitative methods and instruments to characterize and measure students' learning experiences. In order to understand whether a student learned something from the two activities, we designed a short three-question skills test, which could be given before the activities (pre-test) and after the activities (post-test).

Qualitative data (such as interviews and student notebooks) were also collected from both studies and will be the focus of future research that helps us to probe deeper into both learning experiences. The experiment used in this study was approved by the University of Canterbury

Human Ethics Committee (Refer to Appendix B2). The following subsections briefly describe the student population, the details of each activity and the design and marking of the skills test.

4.2.1 The Student Populations

Our two study populations (field and videogame) were made up of mostly 3rd and 4th year (Masters) geology students, with a subset of non-geology science majors (e.g., environmental science, or biology). Forty students participated in the field study and twenty-five students participated in the videogame study. Thirteen of the students from the field study also played the videogame. This allowed us to compare their individual test results and overall experience with both activities.

4.2.2 The Field Study

The field study consisted of a roughly 1-hour activity at the beginning of a typical field trip day at the Hochstetter Pool at Orakei Korako on February 2nd and 3rd, 2012. The class was split up into two groups with ~25 students and three different instructors. The three instructors were briefed with a specific set of tasks and 'rules' to allow us to control the content (i.e., how much and what kind of information was given) and context (i.e., how much reasoning and relationships are explored) under which the tasks were taught at the hot spring.

The field activity began by asking the students to describe the overall/surrounding geology and then leading them to describe the water, sinter and vegetation properties of the locality. Many of the observations (such as colour, clarity and activity of the water) were 'new' types of observations to make at a field site for many of the students. After students made location sketches and observations, one of the instructors illustrated how to measure the conductivity, temperature, pH and take a sample of the water to send to a laboratory for chemical analysis. The activity concluded with a ‘summary log’ (on the back of their notebooks) of each observation type where the professors ask aloud to the entire class: “What is the ‘right answer’ for this particular field site?”

During the activity, instructors encouraged students to ask questions and were allowed to engage in normal field trip discussions. The education researchers were present to observe and record the tasks as well as the instructor-student interactions. It should be acknowledged that this style of teaching is not ideal for some instructors. These barriers were, however, set in place to allow us a more confident direct comparison with the tasks statically engineered into the videogame. This was intended to decrease the unknown variables that could affect the overall learning experience.

4.2.3 The GeoThermal World Videogame Study

The videogame study consisted of many 1-1.5 hour lab-style sessions where 1-6 students played individually and in pairs over several days in June 7th, 8thand 12th, 2012. The computers were set-up adjacent to one another in a typical computer room/lab setting. Video observations were recorded to follow the behaviour and student language use during their experience with the game. The game is designed to be self-run, but students were instructed that they could ask us (the researchers) and the other students in the room questions if they wanted to.

The videogame begins with a fly-through of the ‘World’ around an active volcano and into a field site adjacent to a small town. The student geologist is told that their ‘Mission’ is to explore the geothermal features and balance environmental concerns with economic/industry concerns of the company for which they are now employed. With little intervention, the students are guided to make their own observations of the Sapphire Pools: a. take photographs and b. measure quantitative data, just as in the field study. Familiar tools were created for the videogame such as: a GPS, geologic notebook, camera, temperature probe, pH and conductivity probe and ‘hands’ that will safely take a water sample for chemistry. These tools were designed to be as they are in real life, with some modifications to make playing the game more intuitive (refer to Figure 4.3).

Figure 4.3: A screenshot of the Sapphire Pools, with two important tools that were developed for the videogame. (Left) A digital geologic notebook, which has drop-down options (e.g., number of features, etc.) and a section for written observations. (Right) The students' smartphone, which contains hints and contextual information to guide the student through the observations of the hot pools.

The students' progress is guided by several design items such as drop-down options within the digital geologic notebook; 'hover hints' (where a tool is further described by hovering your mouse over the item); a smartphone tool (where the company manager can email the student) to provide context for why they are taking the measurements; and a field assistant (named Hamish) who is located nearby to provide some guidance if the students are stuck. The game concludes when the student has successfully written geologic notes, selected the right observations, measured the highest readings and taken several representative photographs of the field site. Due to time constraints we were unable to include the 'summary log' mission (as performed in the field activity).

4.2.4 The Skills Test

The pre-post skills test was a paper-based test, which was designed and administered to assess the student's knowledge of observation and measuring skills that are needed at a geothermal hot spring before and after the activities. Each question is linked to the learning goals that are set for the activities. It should be mentioned that we are not assessing their ability to make observations, but rather their knowledge of 'what they should do'.

Question 1 consisted of an open-ended, short-answer style question: "Question 1. A. List as many types of visual observation data as you can, that can be collected at a geothermal hot spring. B. For each type of data, write the reasoning for why you collect it (what is the purpose for collecting it?)". Question 1 made up the majority of the marks on the test with twelve correct observation types that should be noted (e.g., the colour of the water, the textures of sinter near the springs and the surrounding geological features, etc.) when thoroughly describing a hot spring. Each observation was awarded 0-1 mark for listing each type (Question 1a.) and 0-3 marks for the reasoning provided (Question 1b.) for a total of 48 marks. This style of question (open-ended; short answer) was chosen purposely and allows us to probe specific student responses for not only awareness of items, but the depth of their responses which is not possible with multiple-choice style questions.

Question 2 was made up of three multiple-choice questions (worth 2 marks each), which asked the student to locate places on a diagram of a hot spring to safely and accurately take temperature and conductivity readings, as well as identifying what white-coloured material may be surrounding a high temperature pool.

Question 3 asked: "Of the following, which is NOT an effective method when sampling &/or visiting geothermal hot springs?" Of the nine options, the incorrect responses were: 1. tasting a small amount of the water; 2. digging in the ground adjacent to the hot spring and 3. taking 10 pH readings.

Testing conditions at Orakei Korako were not entirely controlled as it was given in the field, with some noise and visual distractions that come from being at a tourist location. However, in both studies all of the students were given as much time as needed to take the tests (most students completed them in approximately 15 minutes) and were not allowed to share their responses with others.

4.2.5 Marking the Skills Test

Question 1 is an open-ended question and in order to mark it objectively, a 'rubric' was designed to award students for A. listing the correct items and for B. showing a high and/or low level of understanding of why we collect this sort of data. A rubric refers to a set of guidelines/criteria used to grade students uniformly, in what is considered a qualitative assessment (with more inherent subjectivity) (Arter and McTighe 2001). Different marks were awarded based on the level of sophistication reached for each category (e.g., poor, adequate, good and excellent). The well-designed rubric helped the marker to be unbiased and consistent when considering all the responses.

For example, two students are asked to explain why we observe water clarity at hot springs: Student A (low-level) simply wrote: “composition”. They received 0.5 out of 3 marks. While Student B (high-level) wrote: “[transparency] of fluids, how clear is the water? [It] can indicate [the] amount of material in solution and this [can] be a proxy for temp[erature] (higher T = more dissolved, less cloudy)”. This response received 2.5 out of 3 marks.

Marking the multiple choice questions (Questions 2, 3) was straightforward with either correct (2 marks) or incorrect (0 marks) responses noted.

4.3 RESULTS & IMPLICATIONS

Hake (1998) published a seminal work that provided education researchers with a sound metric that normalizes each student’s individualized learning ‘change’. ‘Learning gains’ (commonly shortened to ‘gains’) are calculated by:

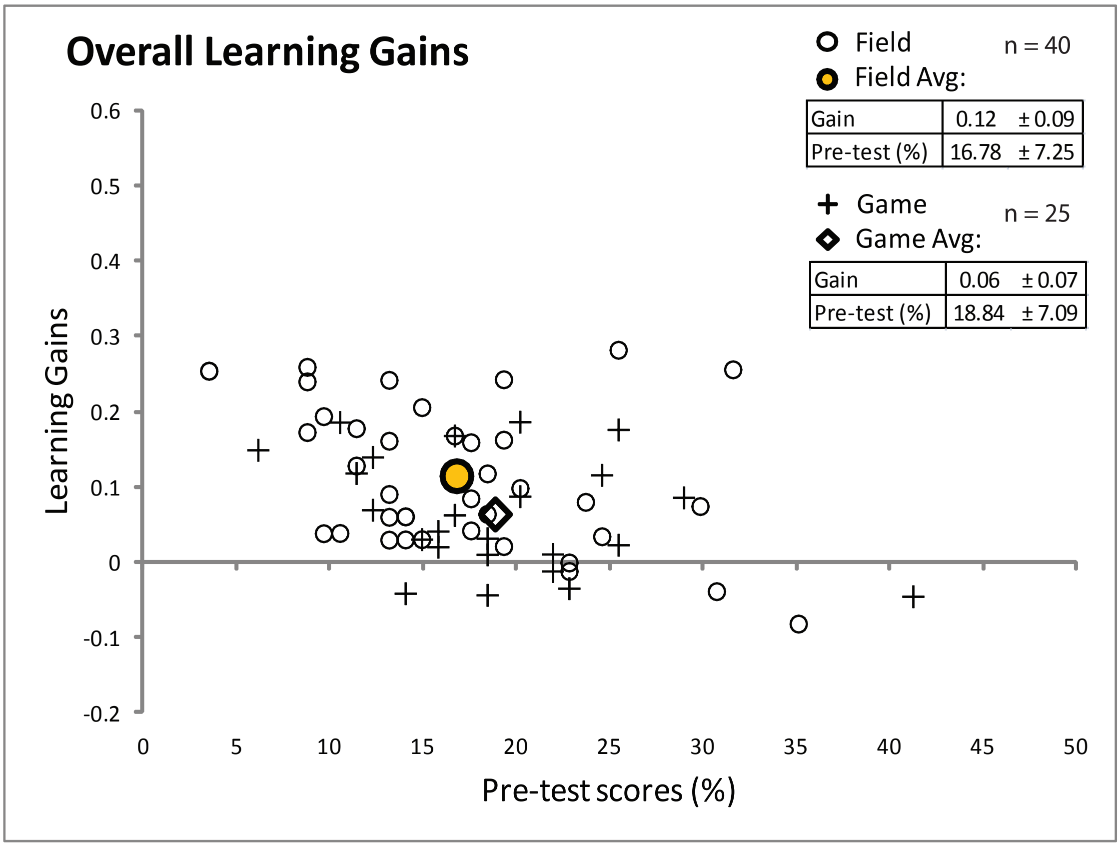
$$\text{Learning Gains} = \frac{(Posttest\ \% - Pretest\%)}{(100\% - Pretest\%)}$$

Positive gains indicate that the student in question scored higher on the post-test than on the pre-test. Negative gains indicate the opposite. For example: Student A receives a pre-test score of 30 percent and a post-test score of 44 percent. This results in a 0.2 gain. Student B receives 80 percent on the pre-test and 84 percent on the post-test resulting in same gain (of 0.2). The change in learning is dependent on each student’s individualized ‘starting point’. Normalizing the change in test scores allows us to compare them to one another and assess whether or how much they ‘learned’. Averaging an entire population will show whether the majority of students acquired positive learning gains, or negative ones. Comparing learning gains with pre-test or post-test scores also allows differentiation of the experience’s effect on specific demographic groups within the study population; or between two disparate teaching methods.

4.3.2 Results: Overall Learning Gains

We set out to test whether a videogame could be used to teach field skills as effectively as a real world field activity. Overall, the skills test results indicated that both learning activities are capable of generating positive learning experiences. The change in student skills test scores from the field was marginally greater than for the videogame. Learning gains with the field activity (0.12 ± 0.09) reached slightly higher totals (Figure 4.4) than the videogame (0.06 ± 0.07). Elkins and Elkins (2007) note that the field teaching typically results in higher learning gains of concepts when compared to traditional lecturing techniques. The data from this study also suggests that students can have positive learning gains from field learning, which are equivalent to the videogame we have designed.

Figure 4.4: A learning gains versus pre-test score plot of the concept tests. The two study populations are shown (Field, circles; and Videogame, crosses) as well as their averages. Overall, both learning activities resulted in positive learning gains implying that the students 'learned something'. The Field activity resulted in marginally higher learning gains (on average).



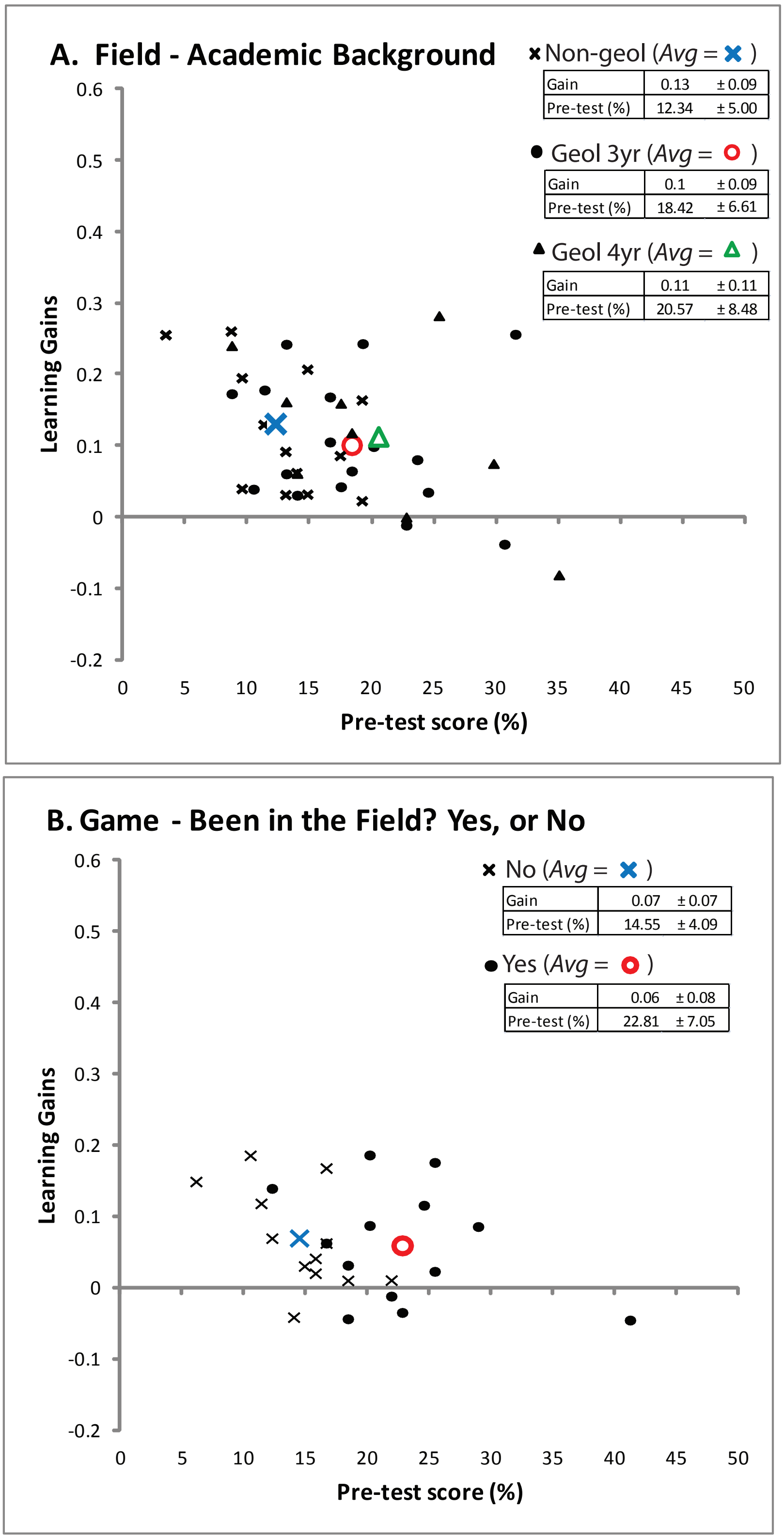
4.3.3 Student Demographics

Aside from overall (average) learning gains, it is helpful to plot specific demographic groups within each population to determine if they were affected by the activities in different ways. We categorized the skills test data into: 1. Age; 2. Gender; 3. Academic background; 4. Field experience; and 5. Videogame experience.

No significant correlations were found, which indicates that learning gains (and the students' learning experiences) were not affected differentially by the above parameters. Two associations are worth noting however. Figure 4.5A shows a plot of the field results, sorted by the students major and experience (e.g., geology majors, 3rd yr). Figure 4.5B shows a plot of the videogame results, sorted by whether the student went to Orakei Korako ("Yes") or not ("No"). On average for both of these plots, the students learning gains are similar, but the pre-test values are not.

This implies that regardless of the student's discipline, their pre-existing skill set, or their previous experiences achieved equivalent learning gains occurred. Previous research has shown that 'gamers' may succeed in videogame tasks while 'non-gamers' often do not (Brown et al. 1997). Several of our participants who stated that they "Never" or "Sometimes" played videogames achieved some of the highest gains from the study group. Based on these preliminary findings, we are confident that our game design is successful for teaching people from all backgrounds about geothermal hot springs.

Figure 4.5: A. A gains versus pre-test plot of the field study data which has been sorted based on the students' academic background. Note that the non-geology majors had a smaller pre-test score, but (on average) had equivalent gains. B. A gains versus pre-test plot of the videogame study data. Here, the students are sorted into groups that were field study (Answered: "Yes") and those who were not ("No"). Again, this illustrates that they came into the study with less knowledge (lower pre-test score) but achieved equivalent gains.



4.3.4 Item Analysis of Question 1 - Observations

A breakdown of the student's responses to Question 1 further support the idea that both learning activities were successful at increasing the students' knowledge about observing hot springs. There are two elements that we can derive from the student's responses of Question 1: A. Whether particular categories/items of observation were known to them, or became known to them (i.e., awareness) after the activity (e.g., did they list 'colour' in the post-test, but not in the pre-test?) and B. Did the student's reasoning become more sophisticated between the pre-test and post-tests? (i.e., inferring a change in the depth of their understanding; represented by a spectrum of marks between 0 (low) to 3 (high)).

The responses from both study populations were collated (for each student) and it appears that both were effective in creating awareness of the types of observations that scientists record at hot springs (Table 4.1). The overall positive change in the number of students' awareness of observations was almost identical (averages of 13% (field) and 12% change (game)). This again showed that the game was equally successful at teaching students to know what to look for when making observations at geothermal areas. The videogame showed improvement across more categories than the field activity, although the field activity showed bigger improvements in some categories.

The field was highly successful at bringing awareness to the water properties, notably the activity of the hot springs (change of 65%!), which is likely due to a sensory effect (seeing the boiling water, hearing it, smelling it), it being a novel (or new) observation to be taken; or that the instructors may have focused (spent more time) on this observation. The videogame, on the other hand, showed more successful changes with the close-up surrounding features (e.g., sinter textures, algae and vegetation). This is likely due to the explicit nature of the game (in addressing each observation in turn; allowing students to derive what they feel is important) while field teaching tends towards being more holistic and less explicit in nature.

Generally, both activities were less successful (i.e., had negative or negligible values) at bringing awareness to the other geological information and classification of the features. Negative values could indicate that students thought these types of observations were less important to focus on, or note. Alternatively, it may be that the students shifted their focus onto the most immediate/important observations (what are the properties of the water?). This result is surprising, as field activities are usually better at teaching contextual information. Classification in particular was not the focus (or one of the major learning goals) of the activities, but will be the focus of future field research and videogame levels.

Table 4.1: Changes in Awareness

The values below represent the changes in 'awareness' that were recorded in categories of observations that the students exhibited, from Question 1 of the skills test. Orange values represent >10% (positive) changes of awareness and blue values represent >-10% (negative) changes of awareness.

Change in Awareness of Items to Observe

		Field (n = 40)			Game (n = 20)		
	Items:	Pre (%)	Post (%)	Change	Pre (%)	Post (%)	Change
Water properties	Colour	30	58	**28**	39	70	**30**
	Clarity	5	70	**65**	29	52	**24**
	Smell	3	25	**23**	21	43	**22**
	Activity of the feature	68	83	**15**	68	83	**15**
Close-up	Mineralogy	55	58	2	32	4	***-28***
	Sinter	18	18	0	29	52	**24**
	Algae	18	25	8	14	39	**25**
	Vegetation	25	60	**35**	36	48	**12**
Other	Number of springs	8	15	8	21	26	5
	Size of springs	35	20	***-15***	18	17	0
	Other geological info	68	53	***-15***	43	52	9
	Classification	23	20	-3	14	22	7
			Total Avg	**13**		Total Avg	**12**

Table 4.2: Changes in Sophistication of Response

The values below represent the changes in 'depth' or sophistication that were recorded in categories of observations that the students exhibited, from Question 1 of the skills test. Orange values represent >0.1 (positive) changes and blue values represent >-0.1 (negative) changes in the depth of reasoning that the students used in that category.

Change in Sophistication of Response

	Items:	**Field (n = 40)** Pre (Avg)	Post (Avg)	Change	**Game (n = 20)** Pre (Avg)	Post (Avg)	Change
Water properties	**Colour**	0.13	0.46	**0.34**	0.41	0.57	**0.15**
	Clarity	0.04	0.51	**0.48**	0.21	0.50	**0.29**
	Smell	0.03	0.26	**0.24**	0.11	0.43	**0.33**
	Activity of the feature	0.46	0.65	**0.19**	0.36	0.39	0.03
Close-up	**Mineralogy**	0.36	0.35	-0.01	0.23	0.00	***-0.23***
	Sinter	0.13	0.19	0.06	0.18	0.24	0.06
	Algae	0.08	0.20	**0.13**	0.07	0.26	**0.19**
	Vegetation	0.18	0.48	**0.30**	0.29	0.28	0.00
Other	**Number of springs**	0.04	0.09	0.05	0.11	0.20	0.09
	Size of springs	0.16	0.14	-0.03	0.00	0.09	0.09
	Other geological info	0.69	0.48	***-0.21***	0.29	0.41	**0.13**
	Classification	0.11	0.24	**0.13**	0.07	0.13	0.06
			Total Avg	**0.14**		**Total Avg**	**0.10**

Table 4.2 lists the changes in ‘sophistication’ or depth of student responses after participating in the learning activities. Categories with higher averages had more ‘high level responses’ (e.g., marks of 2.5 or 3). Overall, the field activity was slightly more effective at students developing a deeper understanding of why they make particular observations (with an average of 0.14 for the field and 0.1 for the videogame).

Both activities were successful at ‘deepening’ the students’ knowledge around water properties (e.g., colour, clarity and smell). The field was more successful at deepening students’ understanding in most categories; the game showed more improvement than the field at smell, algae and other geological information. Based on our current understanding of field learning, it is not surprising that most categories were better/deeper understood from the field activity. Classification was better understood in the field and this shows the strengths behind following the highly contextualised nature of field learning. As the videogame was not designed to delve into chemistries and classification of hot springs, it is reasonable that values for this category are not significant.

It is interesting to note that a videogame (virtually-constructed) was actually more successful in teaching students about why smell is relevant to observe at hot springs. In order to create ‘smell’, we put ‘word clouds’ that would pop-up over the steaming water with the words: ‘Eggy’. Text within their Smartphone would help explain why egg smell is related to H_2S emissions; and generally why we observe smell at hot springs. Regardless of the limitations of technology, the students appeared to pick up this information and develop an understanding of this method.

The depth of their understanding is also likely to be directly related to how much context was provided as to why they are collecting particular observations. Although we provided a script to the instructors in the field, it was common for some student questions/ and instructor responses to become more in depth than was comparably provided in the videogame. This shows the strength of field teaching in that a student may want to know why they are doing something and a lecturer can immediately respond with contextual reasoning. Conversely a videogame is limited to what information can be embedded and the style is of discovery (i.e., inquiry-based learning) where a student interacts and comes to conclusions on his or her own. This may leave some contextual information hidden and not picked up by students who are not looking for it.

4.3.5 Limitations

Rigorous quantitative research requires larger study populations (or n values) to improve confidence in the validity and reliability of the overall results. Validating the skills test would also provide more confidence in the results from this study. Subsequent research will be designed to explore these factors.

Another issue that we noticed is a phenomena called “testing fatigue” or “test sensitization” (Cohen, Manion and Morrison 2007; pg 214). Results from the group of students who participated in both studies showed an obvious lack of effort in several of the students’ responses. This resulted in less sophisticated responses and, therefore, smaller post-test scores. This was noted for two participants in the field study (post-tests) and six students in the videogame study (some pre- and post-tests). Therefore, the average learning gains achieved can be considered a minimum for both activities. Further testing with new participants should allow us to better constrain the overall learning gains in both settings, but particularly the videogame.

4.4 CONCLUSIONS & FUTURE WORK

Our comparative study of The GeoThermal World videogame versus the Orakei Korako field activity has shown that a videogame can be just as successful at increasing students' knowledge and depth of understanding of observation skills in geothermal geology.

Although the field achieved higher overall learning gains, it appears that some aspects of the videogame were more successful such as teaching awareness of ALL the observations that are useful at geothermal hot springs (e.g., sinter, algae and vegetation). It may be that the field presents additional distractions that are not present 'in' a videogame. The sensory overload may actually inhibit students from focusing on each observation. Further research into the students' attitudes and geologic notebooks should illuminate many other aspects which impact learning in the field.

The major drawbacks or limitations to the videogame may be in achieving 'depth' to students understanding of some topics. Inherently, a student may only learn about – what is included in the videogame. This is especially true for visual and contextual information. The Sapphire pools were located at the base of an active volcano. Some students observed this important fact, while others were so focused on the tasks that they missed the context entirely. The solution is to make explicit sub-tasks (or missions) to pay attention to the bigger picture.

As of yet, we have only designed the first level of the GeoThermal World Videogame. Several other virtual field sites (acid sulphate; and bicarbonate) are mapped and planned within the World. Theoretically, the more time spent inside the context of the videogame and the more diversity that the student experiences the deeper the students' understanding of geothermal geology.

For the best possible results, we recommend using GeoThermal World to teach students the basics of geothermal hot spring observations prior to going out into the field. Allowing them to play with these ideas prior to implementing them in real life (with all its distractions and complications) may encourage more sophistication in the field.

CHAPTER 5: SCENARIO-BASED ROLE-PLAY: DESIGN RESEARCH OF THE VOLCANIC HAZARDS SIMULATION

PREFACE

(Photo by Elle Emery; Girl seated on Mt. Ruapehu looking south-west towards Mt. Taranaki)

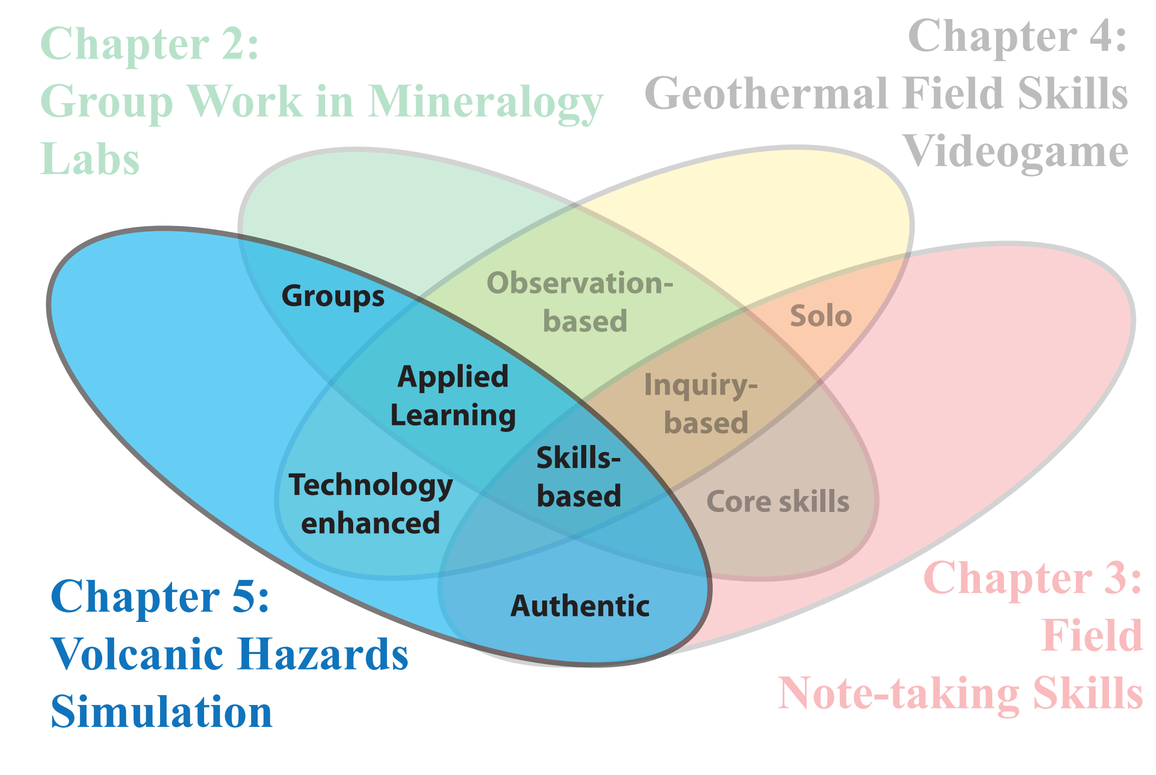
Chapter 5 discusses the iterative design of the volcanic hazards simulation and its effect on student behaviour. The development of this simulation occurred over the three years of my doctoral research that was influenced by my experiences coping with the Canterbury earthquakes and living in pre- and post-quake Christchurch. Living through these major seismic events has taught me many things about seismology, emergency management, psychology and politics of recovery and myself.

This study used a combined learning approach with aspects of ***authentic learning***, ***situated learning***, ***role-play*** and ***simulation***. These learning approaches complement one another in an ***applied***, ***scenario-based*** learning activity. The many ***goals*** that were set out for this learning activity were ***scaffolded*** from the earlier parts of the simulation to the later parts. The main goals were to enhance students' ***transferable*** and ***geologic skills*** that are needed in a crisis scenario.

Another important teaching approach was ***group*** (or in this case, ***team***) learning pedagogy. Aspects of Chapter 2 were revisited around positive and negative group dynamics that occur when students are forced to work together. These approaches are underpinned from ***motivational*** and ***cognitive load*** theories that arise from learning in complex, real-life settings. These educational theories guided the overall curriculum design process and resulted in a highly challenging and engaging learning experience for the instructors and students involved in its evolution.

Figure 5.1: Theoretical concepts (top) and learning strategies (bottom) which are discussed in Chapter 5.

	Chapter 2	Chapter 3	Chapter 4	Chapter 5
Goals-based Curriculum Design	✓	✓	✓	✓
Authentic Learning Environment		✓	✓	✓
Cognitive Load Theory	✓	✓	✓	✓
Novelty Space		✓	✓	



5.1 INTRODUCTION

An interactive, face-to-face role-play simulation was designed with the purpose of teaching tertiary geoscience students the skills and concepts necessary to predict and mitigate a volcanic crisis. One part of the activity is focused on recording, processing and interpreting real volcano monitoring data (e.g., seismographs, gas output, etc.), while the other is to manage and mitigate the effects of volcanic eruptions on local communities.

Our learning outcomes were centred on transferable skills: teamwork, communication and decision-making during a crisis scenario. We presented students with an authentic scenario and with relevant future career opportunities related to solving that scenario. Transferable skills in the natural hazards sector are essential and they align with the needs of other sectors such as engineering, medical sciences and management sciences. To acquire and perfect these skills, students need to practice them in authentic scenarios. Cox, Cekic, Ahn and Zhu (2012) suggests that, “engaging students in authentic projects that will allow them to explore the implications of their work for engineering and for other sectors (e.g., the larger society)... [to] engage in projects that relate to engagement with diverse stakeholders” (Cox et al. 2012, page 68)

The geoscience and engineering community have recognized the deficit of quality teamwork and communication skills in their graduates (Dannels, 2002; Heath, 2000, 2003; Ireton, Mogk and Manduca 1997; McMasters and Matsch 1996; Sageev and Romanowski 2001; Seat, Parsons and Poppen 2001). These competency gaps in science, engineering and technology students specifically deal with “information sharing” and cooperation, as well as ethical decision making and behaviour (Meier, Williams and Humphreys 2000).

For this role-play-based scenario, the best practices for teamwork and communication were developed alongside the simulation design and were derived from the Natural Hazards science and Emergency Management Sector in New Zealand. These were obtained via interviews and consultation with volcanic hazards professionals at the Geological and Nuclear Sciences of New Zealand Science (GNS, i.e., GeoNet) and the Civil Defense and Emergency Management sector.

The simulation discussed in this chapter was examined using a design-based approach. Design-based approach is often used when an activity is complex and has many interacting variables. Because, it is difficult to track individualized experiences in these activities, the researcher must sort through the multitude of variables in order to see the themes emerge. Therefore, design-based research is not so much *an* approach as it is a series of approaches, with the intent of producing new theories, artifacts and practices that account for and potentially affect learning and teaching in naturalistic settings (Barab and Squire 2004; van den Akker 2006).

The simulation development followed an iterative process of re-design over three years with close guidance from the instructors of the intended courses. The careful balance of authenticity and learning-goals-based pedagogy guided the changes made in each iteration. The original simulation design was based on Harpp and Sweeney (2002) and the development process was guided by the real protocols and role structure of GNS and Emergency Management sectors in New Zealand. We drew from the literature in these sectors in order to address the necessary components of an emergency response to successfully mitigate the impact of the disaster. We anticipated that by modelling authentic practice, students should develop an appreciation of the complex range of difficult tasks that geoscientists undertake during a natural disaster. The Volcanic Hazards Simulation is a multi-faceted learning activity that incorporates elements of several well-studied pedagogies described in detail below: A. simulation, B. role-play and C. group (or team) learning.

Simulations can be described as learning experiences within an imaginary or virtual system or world (Van Ments 1999). Role play is predominantly concerned with the importance and interactivity of roles in pre-defined scenarios (Errington 1997; Errington 2011). Role-play and simulation pedagogies overlap and are complimentary learning strategies (Milroy 1982). Group learning is an experience in which participants learn through the processes and outcomes of the group interaction (Turner 2000). In this context, group learning is embedded within the role-play simulation through paired and group discussions, meetings, data synthesis and whole-group communication (i.e., press conferences). These pedagogies are grounded in active, situated, experiential and social constructivist learning theories that encourage dynamic student-centered learning. As a result, they require more active participation from students than traditional teaching techniques (i.e., lecture-based, “stand-and-deliver”, passive) and intend to teach practical and theoretical skills that are transferable to different future situations (e.g., Roth and Roychoudhury 1993; Lunce 2006).

The aims of this chapter are to: 1) assess whether a volcanic role-play simulation designed for 3rd and 4th year geology students achieves transferable learning goals and 2) describe the iterative rigorous pedagogical process of simulation development that can be applied to the development of other scientific role-play simulations.

The Volcanic Hazards Simulation is primarily a role-play learning activity. Students were assigned to roles for two main pedagogical purposes: 1) to provide task structure (i.e., dividing the workload) and 2) to allow students to experience a particular role with its responsibilities (and possible future career). A summary of the detailed learning goals that were delivered to the students during all iterations can be found in Table 5.1. We will discuss the following four major design variables that were explored during the development process:

1. Pace: Optimize the pace of the activities to create an engaging but manageable task environment.
2. Preparation activities: Provide scaffolding of the roles, teams and geoscience concepts needed through preparation activities completed prior to the simulation to lessen cognitive load and increase the students' confidence.
3. Authenticity: Increase the authenticity of the roles, teams and interaction of both in order to demonstrate authentic behaviour and make relevant the need for quality teamwork and communication skills.
4. Communication Skills: Model science communication best practices to increase student autonomy of the students and, thus, ensure success through increased communication skills capability and quality.

Table 5.1: Learning Goals of the Volcanic Hazards Simulation

After the simulation, students should be able to…

1. Observe volcanic monitoring data and social media in "real-time", **record** observations and **communicate** these observations to a team (orally and in writing).

2. Collaborate within a team, by using multiple streams of data in "real-time" to develop a working-model (inclusive of scientific and social-economic data) together in order to:

- a.) assess the current state of volcanic activity;
- b.) identify major changes in volcanic activity;
- c.) judge if changing conditions threaten the human population;
- d.) use a-c to assign appropriate GNS alert levels;
- e.) respond to community concerns

3. Estimate and **illustrate** the distribution of volcanic products (e.g., volcanic ash) based on the eruptive style (column height and explosivity) in order to **create** volcanic hazard maps using geological and socio-political map data (i.e., geology map, geological history and contoured topographic map).

4. Estimate the impact to social and political sectors based on the distribution and style of volcanic activity, given the alert level of the volcano in question. **Respond** to crises (in a timely manner) in order to mitigate the impact before/during/and after a volcanic disaster.

5. Communicate effectively (orally and written) within your team and to the other teams and to the public (newsfeed) in order to effectively handle any possible volcanic threat. These are assessed by:

- a.) press conferences (questions and responses);
- b.) effective group discussions;
- b.) media releases;
- c.) volcanic impact reports;
- d.) effective inter-agency (between GNS and Emergency Management) conversations and meetings

6. Explain the importance of a.) Scientists and emergency managers responsibilities, agendas and expertise; b.) Team structures, hierarchy and protocols; c.) external agencies that assist Emergency Managers and d.) The public's concerns during a simulated volcanic crisis.

5.2 THEORETICAL FRAMEWORK

In the simplest definition, simulation includes anything that is "played" by the participants set in an exploratory, real world scenario (Blake 1987); these include games, role-plays and simulations (Van Ments 1999). "[Role play requires that] each player acts as part of a social environment… and provides a framework in that they can test out their repertoire of behaviours" (van Ments 1999). Role-play and simulation: a) improves problem-solving and decision-making skills (Errington 1997; Barclay, Renshaw, Taylor and Bilge 2011); b) increases interpersonal interactions (Blake 1987; van Ments 1999; Shearer and Davidhizar 2003); c) positively changes student's attitudes (Shearer and Davidhizar 2003); d) enhances communication skills (Van Ments 1999); and, most importantly e) increases motivation and participation in the learning process (DeNeve and Heppner 1997; Livingstone 1999).

The study of psychology and human behaviour allows educational researchers to unravel processes and principles to create effective learning experiences. Several important theories of human cognition and behaviour were considered during the design of the Volcanic Hazards Simulation:

1. Cognitive load theory (Chandler and Sweller 1991; Sweller, van Merriënboer and Paas 1998);
2. Motivational theories (Ryan and Deci 2000; Eccles and Wigfield 2002; Eccles 2005);
3. Team and group behaviours (Turner 2000; Michaelsen and Sweet 2008) and organizational theory (e.g., Argote, Ingram, Levine and Moreland 2000);
4. Design-based research (Edelson 2002; Barab and Squire 2004; Sandoval and Bell 2004).

5.2.1 Cognitive Load Theory

Learning activities (with associated complex tasks) can be used to impart knowledge, skills and attitudes that are transferable to daily life or work settings (Van Merriënboer, Kirschner and Kester 2003). Authentic real-life tasks contain many constituent tasks, which when presented simultaneously, are overwhelming for a novice learner. The theory of how an individual manages a set of tasks in their working memory is referred to as cognitive load theory (Chandler and Sweller 1991; Sweller 2003).

Research shows that when students cope with learning tasks many intrinsic and extrinsic factors affect motivation, perceptions and performance (Matsumoto and Sanders 1988; Eccles and Wigfield 2002). Characteristics of the task itself such as the level of complexity (van Merrienboer, Kester and Paas 2006; Kirschener, Paas and Kirschner 2009), perceived difficulty (Kuhl and Blankenship 1979; Slade and Rush 1991), length of the task (Peterson and Peterson 1959) and task interconnectivity (Van Merriënboer, Kester and Paas 2006) all affect the cognitive load of a given learning activity.

In order to design effective instructional materials, cognitive load should be considered in order to adjust the design to best meet the learning goals. An effective approach is to prepare students by scaffolding the discrete topics and skill sets prior to and during the simulation. Scaffolds include all devices or strategies that support students' learning (Rosenshine and Meister 1992). The support enables a learner to reduce their cognitive loads and achieve their goals. Gradually, support can be reduced as students learn to cope with increased cognitive load (Van Merriënboer, Kirschner and Kester 2003).

5.2.2 Motivational Theories

An additional educational psychology concept relevant to our design is the theory of motivation. At its simplest level, motivation is to strive for something. An individual's motivations in educational endeavours primarily stem from feelings of recognition, responsibility, personal growth, autonomy and overcoming challenges (Beard 1972). If the learning activity is realistic and the tasks are perceived as personally useful each student will weigh the value (consciously or subconsciously) of participating as part of his or her long term academic and professional development (Eccles and Wigfield 2002; Eccles 2005).

Situated learning experiences are more effective means of learning complex tasks and include authentic contexts, activities, multiple roles and perspectives, supportive collaborative construction of knowledge (Herrington and Oliver 1995). Students can view situated applied projects as important to their careers as academics or industry geologists, which is also linked with financial outcomes (e.g., Santi and Higgins 2005; Godfrey, Barrett and Godfrey 2011) and therefore perceived as directly useful for their futures and are motivated to learn (Anderson, Reder and Simon 1996). Motivational considerations are complimentary to other pedagogical considerations, but it can be challenging to integrate them with logistical constraints, as situated learning can significantly affect teaching resources and time.

5.2.3 Team and Group Behaviours and Organisational Theory

Another major influence in our design stems from management and organisational studies involving team-based learning and performance. As a complex simulation, the workings of the learning activity are heavily influenced by the behaviour of individuals within an interactive team environment. There are several key interdependent elements that an effective team must have: A. team members must be aware of and share task and value-based goals (Chou et al. 2008); B. team members must be worthy of trust (trustworthiness) and show trust for other members (trustfulness) (Webber 2002; Chou et al. 2008); and C. people need to feel satisfied by the other members work (Chou et al. 2008) which results in a joint potency or belief in the team (Campion, Papper and Medsker 1996). Negative team behaviour arises when there is a substantial rift in any of any of the above elements. Further definition of how these theories were incorporated is discussed with the results in the discussion section of the paper.

5.2.4 Design-based Research

The development of the Volcanic Hazards Simulation was an organic, iterative design process guided by design-based research literature. Student and instructor behaviours and perceptions were collected through a broad and descriptive study focused on qualitative thematic methods (e.g., Miles and Huberman 1984). Design-based research (i.e., "design experiment" or "development") research is theoretically framed, empirical research of learning and teaching based on particular designs for instruction (Barab and Squire 2004; Sandoval and Bell 2004; Edelson 2002). The design-based research paradigm (e.g., Barab and Squire 2004) incorporates the participants' behaviour (actions, decisions) and their perceptions of these behaviours into the development of the learning activity. This approach is appropriate to our research, as the learning activity developed is new and its design (and therefore, its effect) was untested.

There are a multitude of approaches to the development of a role-play simulation with numerous variables to be considered. The *modus operandi* of design-based research provides a flexible, interconnected, complex line of inquiry that is required to understand the environment, input, social dynamics and outputs of the simulation (Brown 1992). Figure 5.2 (adapted from Walker 2006) illustrates how a typical design process should be implemented, what aspects are important to consider and how that leads to more robust research and outcomes. This iterative, but flexible, approach allows the researcher to be mindful of change while exploring new outcomes and illustrates how research improves practice.

Figure 5.2: The following is adapted from a diagram in Walker (2006). It illustrates the overall context for design research including how research improves practice. This iterative, but flexible, approach allows the researcher to be mindful of change while exploring new outcomes, which could be useful in other contexts.

How Design Research Improves Practice & Theory

(leads to) **More, better learning**

Design research on strong, better **indicators**

(leads to) **Improved** practices and policies

Design research on first generation interventions

(leads to) **Interventions**

Design research with **rigorous** approaches

In order to plan effectively and to design a simulation that fulfills the desired learning outcomes, the instructor should make an inventory of the learning goals that are appropriate to the topic, environment and student participants. Table 5.2 (below) is an example of a comprehensive list of scenarios, settings, conditions and accompanying design variables that can be used in role-play. The highlighted parts of Table 5.2 (grey colour) were all identified as being relevant in the design of the Volcanic Hazards Simulation.

Several previous studies have reported designs of role-play simulations in the geosciences. Researchers have used the natural hazards crisis scenario as the narrative for teaching many important transferable and practical skills: 1) importance of science-politics in crises (Hales and Cashman 2008); 2) communication skills (Bales 1967; Hales and Cashman 2008); 3) decision-making skills (Barclay et al. 2011); 4) volcanic eruption forecasting (Harpp and Sweeney 2002); and 5) teamwork (Maddrell 1994; Harpp and Sweeney 2002). Researchers have also utilised role-plays as a means of teaching cognitive learning outcomes (DeNeve and Heppner 1997; Livingstone 1999).

Table 5.2: Role-play Scenarios and Associated Design Variables

Scenarios	**Design Variables**
Students will practice…	**Content/Scenarios**:
Simple scenarios	Design a simple (usually linear) narrative that aims at accomplishing few, learning goals
Complex scenarios	Design a complex narrative that aims at many inter-related goals (affective, cognitive and skills-based)
Role/job behaviour	Include scenarios (structured or unstructured) that focus on the need for appropriate/authentic behaviour.
Applied scenarios	Design a narrative with scenarios designed for students to apply familiar cognitive and skills-based knowledge.
New (exploratory) scenarios	Design a narrative that is meant to introduce ideas/concepts/skills/topics to students.
Sensitive/controversial topics	Include scenarios that create conflict or require role-players to explain or defend sensitive topics.
The **different sides** of a viewpoint	Students are required on more than one role, at different times to see both sides of a perspective.
Ambiguous or "**scripted"** scenarios	Ambiguity of the information requires (*or does not require*) students to produce/or imagine the appropriate actions or attitudes.
Un-aided or **supportive** scenarios	Instructors/participants are asked to support role-players; step-in to help; or leave participants to their own decision-making
"Best practices"	Include introduction of scenarios to practice specific best practices of discipline-based or transferable skills
in particular circumstances…	**Logistics:**
Static (controlled) or **dynamic** conditions	Outcomes of the role-play are either static (structured, controlled) or dynamic (semi-structured to unstructured or open-ended)
Under **time constraints**	Time/pace is controlled and allotted to specific tasks (more time, or less time)
No time constraints	Tasks are not allotted time constraints
"Stop-and-go", or **continuous** conditions	Role play occurs continuously, or is periodically interrupted in order to let players reflect or rest
Multi-tasking or Task delegation	Require players to be presented with several tasks at once, requiring them to multi-task or delegate the task to another player
Relying on **oneself**, or **others** to achieve an outcome	Role-players are set in an independent or dependent (group) scenarios.
Public or private scenarios	Roles are required to play-out scenarios in a (range of) public or in private (one-on-one with instructors, tutors or in pairs)
while playing (in)…	**Roles:**
"Real-life" roles	Include roles in the simulation that values, agenda and responsibilities are realistic.
Themselves	Include roles that purpose is to act out personally-driven agendas, attitudes or emotions.
"Real-life" Role hierarchies	Include roles within an organized structure, that is near-real life.
Inter-Role interactions	Include roles and scenarios that focus on informal and formal interactions and behavior

*Compiled from Van Ments (1999) and Blake (1987) with additions from the results of this study

5.2.5 Communication & Natural Disasters

During simulated or real natural hazards crises, geoscientists and emergency managers work together to assess the scientific, commercial, environmental, political and cultural interests of their community (Fiske 1984; Voight 1990). Failures such as the Nevada Del Ruiz disaster (Sigurdsson and Carey 1986) and L'Aquila Earthquake tragedy (Jordan et al. 2011) highlight the difficult and crucial role that scientists play in disaster communication and mitigation. In L'Aquila, Italy a civil servant miscommunicated to the public the likelihood and impacts that the region may experience following a small swarm of earthquakes and preceding a 6.3 quake which killed ~300 and left ~65,000 homeless (Jordan et al. 2011). Major successes have equally illustrated the power of sound communication between scientists, emergency managers and the public (e.g., eruptions of Pinatubo, 1991-1992, c.f., Tayag et al. 1996).

A disaster "event" is a complex socio-technical problem in that social, organisational and technical processes interact in a dynamic manner (Wisner et al. 2003). Disaster management is a cyclic and collaborative process in that the gathering together, organisation and dissemination of information and data are critical (Santos-Reyes and Beard 2010). Effective communication is identified as a key practice in creating more disaster resilient communities (Tully 2007; Bryner, Norris and Fleming 2012). Crisis communication research and practice has focused on how the message is delivered, distributed (accurately, timely) and relevancy during an event (Valenti and Wilkins 1995; Seeger 2006; Garcia and Fearnley 2012; Fearnley et al. 2012). Table 5.3 summarizes some of the key aspects of communication during disasters.

Table 5.3: Important Elements of Communication During Disasters

The four channels of information flow during a disaster (Sagun, Bouchlaghem and Anumba 2009)	**Potential pitfalls with information flow during a disaster** (Sagun, Bouchlaghem and Anumba 2009)	**Crisis Communication best practices** (Seeger 2006)
Within each participating organization	Information overload	Treating the public as a “partner”; taking into account their concerns
Between organizations	Dissemination and distribution of the incorrect information	Using honest communication that acknowledges uncertainty
From people (the public) to organizations	Constantly changing information	Working pro-actively with the media
From organizations to people (the public)	Conflicting information	Providing concrete actions that the public can take

An excerpt from Celik and Corbacioglu (2010) illustrates the importance, interconnectivity and complexity of information transfer in a disaster situation:

> “A disaster management system involves many interacting organisational elements that create complexity... In such a complex system, acquiring relevant information and exchanging it among multiple emergency management organisations from different jurisdictions are vital. If a sub-unit of the system fails to attain or transmit the required information, the whole system will likely fail to adapt to the requirements of the risk environments in that it operates... The success of a whole system is associated with the quantity and quality of information that flows among the connected units” (Celik, 2010, pg 138-139).

These fundamental emergency management principles have guided this study throughout the design process.

5.3 METHODS

The data collection for this study is summarised in Table 5.4. We have run five iterations of the simulation over a three-year study period with an evolving curricular design guided by consultation with instructors, professionals and students. The pedagogical design variables are discussed in detail in Section 5.4. In order to ascertain if our design was effective, we collected and analysed student feedback (through interviews and questionnaires) and behaviour (self-reported through feedback and questionnaires; observed by researchers). This allowed us to characterise the successes or failures of our design. The details of data collection and analysis are shown below.

Table 5.4: Volcanic Hazards Simulation Qualitative Data Collection Summary

	Pilot	**Iteration 1**	**Iteration 2**	**Iteration 3**	**Iteration 4**
n of students	12	27	26	23	20
n of instructors	5	7	5	7	6
n of teams	1	3	2	2	2
data used in this study	observations (written)	observations (video-taped)	observations (written)	observations (video-taped)	observations (video-taped)
	post-interview (unstructured) n=8; 3 instructors, 5 students	post-interviews (structured) Appendix D1 n=22 post-interview with 2 instructors (unstructured)	post-questionnaire Appendix D2.1 n =26	post-questionnaire Appendix D2.2 n=22	post-questionnaire Appendix D2.2 n=20
Activity was embedded in…	field course	lecture course	field course	field course	lecture course

5.3.1 Student Participants

The participants for our study ranged in age, gender, nationality, race and previous geoscience experience. A total of 108 students have participated in the Volcanic Hazards Simulation. The simulation was designed for 3rd-4th stage (i.e., academic year) geoscience students, typically between 19-22 years old. The iterations were run with mixed cohorts of American study-abroad students (Pilot, Iteration 2, 3) and New Zealand students (Iteration 1-4).

5.3.2 Observations and Design Process

Data Collection

The entire design process was recorded through summaries of each simulation design and its components. Every major design change and a theoretical and practical justification was recorded and discussed with the instructors of the courses within which the Volcanic Hazards Simulation was used. We collected approximately 37 hours of observation footage that includes 17 hours of simulation activities and an additional 20 hours of pre-simulation activities such as lectures and group exercises. Unfortunately, the hardcopy video files were lost due to the Canterbury earthquakes. Observation summary notes were taken in all iterations, with increments of approximately 2 minute “checks”. Written observations were used primarily for the Pilot and Iteration 2. Observers were introduced to the students and their purpose for being present was explained. Based on these criteria, our observations would be considered “overt” (Jorgensen 1989).

Observations of the Pilot were aimed at reviewing student and instructor behaviour with regard to the core elements of the simulation pedagogy. Several questions were set out that would help us characterise the learning experience: 1. What is the simulation trying to achieve? 2. What are the individual students' behaviours? 3. How are the teams or groups behaving? 4. How are the instructors behaving? 5. Are they supporting the learning goals that were set out? 6. What elements support learning and what elements may be detrimental to learning?

Observations of the remaining iterations were more focused on specific design variables: 1. How does the pace of the simulation effect the success of the simulation? 2. Are students prepared for the tasks presented to them? 3. Does role-play positively affect the student's learning experience and ensure a successful simulation? 4. Does the use and assignment of the roles and structure of the teams ensure a successful simulation? Are more/different roles needed? 5. Characterising the student's teamwork and communication skills. What elements of the simulation create learning opportunities for teamwork and communication? 6. Do the instructors support learning in these new designs?

Almost all of the iterations were done in a multi-room setting and therefore we required multiple observers. This made constant observation of the participants possible. The other researchers (i.e., educational researchers who were doing observations during the simulation) were placed in the other rooms in order to assure all major events and student behaviours were recorded. These researchers were briefed on observation protocol and the main content and behavioural aspects to focus on. Observation notes were discussed and collated with the given researcher within several weeks of the simulation.

Data Analysis

Written summaries of each iteration were collated and analysed for specific lines of inquiry and themes. The primary goal was to document "what happened" and assign a timeline to the student behaviours with accompanying successes and failures of individuals and the teams. These observations were correlated to the student feedback derived from interview and questionnaire data. The purpose of correlation is to match what we observed and how the students perceived those circumstances.

5.3.3 Student and Instructor Unstructured Post-interviews (Pilot)

Due to the exploratory nature of the Pilot, we used informal, unstructured interviews immediately following the simulation with instructors and students to collect feedback. The interviews were in a focus group format where several of the instructors were present along with the students. The two interviews ranged from ~10 minutes to 25 minutes. There were several open questions posed to the participants: 1) What do you think went well? 2) What did not go so well? 3) What can we improve on in the future? and 4) What would you keep the same? These interviews were recorded with an audio recorder and transcribed later for analysis.

Post-analysis of the interviews focused on deriving quotations that were representative of our range in research themes. Specifically, we aimed at characterising the design variables that influenced the overall success of the simulation and the primary learning goals that were fine-tuned with assistance of the instructors. Due to a low n-value (n=8) of participants, saturation (i.e., when data analysis reaches a point where no new themes or insights occur; Corbin and Strauss 1990; Bowen 2008) was likely not achieved for this iteration. However, based on experience with data from the successive iterations, we conclude that the feedback collected was representative of the events (successes and difficulties) observed. The results of these interviews are presented throughout Section 5.4, organized by theme and labelled with “Pilot”.

5.3.4 Semi-structured Post-interviews (Iteration 1)

For evaluation of Iteration 1, we used semi-structured interviews. The interview questions were set out prior to the simulation. These questions are included in Appendix D1. The interviews (n = 22) were conducted by two researchers (Dohaney and Hearne). All of the interviews were audio-recorded and transcribed later for analysis.

Analysis of the 22 interviews began by transcribing and characterising the responses to each question posed. The responses to each question were categorised with reference to the role of the student, their team and their observed behaviour in the simulation. These results were collated and compared to and combined with the post-questionnaire results described in Section 5.3.5. Thematic and response saturation for this specific data set was achieved. This was achieved by constant comparison of original themes that emerged from the Pilot, to each subsequent data set. The data collected in Iteration 1 was the first stage of theme development that continued to be made more evident and verified in the iterations following. These results helped us to recognise the pedagogical design benefits and drawbacks.

5.3.5 Student Post- Questionnaires (Iteration 2, 3 and 4)

There were two feedback questionnaires in this study. The questionnaires (refer to Appendix D2.1 for Iteration 2 questionnaire (n=26); and refer to Appendix D2.2 for Iteration 3 (n=22) and 4 (n=20)) were administered directly following the simulation activities. Students were given unlimited time to fill out the questionnaires. The questions in the questionnaire probed specific aspects of the pedagogy. Our focus in Iteration 2 was to understand the affect of the pace, the nature of role-play and the team structure. Our focus in the questionnaires for Iteration 3 and 4 was to probe into the students' perceptions of communication within the simulation.

Responses within the questionnaires were transcribed, collated and sorted by the relevant research themes. The results from each iteration were compared to and combined with the interview data previously described. Data saturation occurred for the specific themes (i.e., research goals), which were targeted (i.e., research goals) by combining the results from the Pilot and Iteration 1 with the data from Iteration 2, 3, 4. These results helped to narrow the breadth of our themes, which were explored through interviews in the Pilot and Iteration 1, by probing specific qualities of the simulations design and the students' perceptions of their experiences.

The combined results from this iterative study are presented below.

5.4 RESULTS: DESIGN VARIABLES

Like other design-based projects, the iterative development of the Volcanic Hazards Simulation aimed to achieve multiple research goals. The main aim was to design a complex, authentic simulation requiring students to use concepts and skills employed by professionals in the emergency management and volcanic forecasting scientific communities. These concepts and skills are outlined as explicit learning goals (Table 5.1). The purpose of investigating the simulation design was to enable students to better achieve the intended goals. The design variables reported below were considered to be crucial to the overall success of the simulation. The major pedagogical themes are interconnected and overlapping in nature. For example, small changes to students' role assignment may also affect team structure and potentially team dynamics. Therefore, each design variable and its inter-relationships were investigated.
We ran four Iterations following the Pilot. The basic properties of each iteration are shown in Table 5.5.

Table 5.5: Simulation Iteration Basics

	Pilot	Iteration 1	Iteration 2	Iteration 3	Iteration 4
***n* of students**	12	27	26	23	20
***n* of Instructors**	5	7	5	7	6
***n* of Teams**	1	3	2	2	2
Pace	1 day = 1 min real time; 30 eruptions Feb 15th-July 1st 2 pauses	1 day = 1 min real time 26 Eruptions Feb 15th - July 1st 4 Pauses	1 day = 1 min real time 24 Eruptions Mar 1 – Jun 19th 6 Pauses	1 day = 1 min real time 19 Eruptions Mar 1 – Jun 19th 6 Pauses (longer)	1 day = 1 min real time 19 Eruptions Mar 1 – Jun 19th 6 Pauses (longer)
Duration	~ 5 hours	6 hours	6 hours	5.5 hours	5.5 hours

Throughout the development of the simulation, the feedback included a wide range of positive and negative comments. The feedback was balanced with the original design goals. Therefore, each iterative modification decision was a compromise between the scenario authenticity and the learning and design goals of the simulation.

The design decisions implemented were concerned with three theoretical, educational psychology components: 1. cognitive load reduction for the individual students and the collective group; 2) increased role and team authenticity; and 3) improvement of students' communication skills performance and attitudes (Figure 5.3). These theoretical components are grounded in three design variables examined, changed and which led to an overall more successful learning activity. The following sections describe the three major design variables discussed in this study: A. the pace of and preparation prior to the simulation (Section 5.4.2); B. role-play: roles and teams (Section 5.4.3); and C. communication (Section 5.4.4).

Figure 5.3: VHS pedagogical design evolution time line.The development focused on three major components: reducing the individual and collective cognitive load of the students (Iteration 1 & 2); increasing role and team authenticity (Iteration 1 to 3); and improving the students' communication skills (Iteration 3 and 4).

Pilot	**Iteration 1**	**Iteration 2**	**Iteration 3**	**Iteration 4**
Description: Improvised; No structure; 'Chaos'; Frequent intervention from Instructors, Very few prepatory activities	***Description:*** Moderately structured; Major difficulties in specific roles, and breakdown in communications and responsibilities.	***Description***: Very structured, still 'too fast'; Inter communications improve; More role investment and authenticity	***Description***: Same structure as It2; Preparation activities are significantly changed to improve communication skills	***Description:*** Same structure as It2; Preparation activities occur over 1 week, and was set in the classroom rather than the field setting
	Reducing Cognitive Load →			
		Increasing Role Authenticity →		
			Improving Communication →	
Design Focus: No previously defined focus; Improvised, immersive situated-learning experience	***Design Focus:*** Reducing cognitive load issues, reducing 'chaos', providing structured tasks	***Design Focus:*** Continued emphasis to reduce cognitive load & further students immersion into the roles and teams	***Design Focus:*** Whether providing communication best practices improves oral and team communication	***Design Focus:*** Same intent as It3, but communication best practices preparation was delivered in a different setting

5.4.1 The Design of the Pilot

The simulation Pilot was based on Harpp and Sweeney's (2002) volcanic hazards teamwork design by condense in an accelerated time frame. The focus of our simulation was to encourage students to work together, make on-the-fly data interpretation and to advise the New Zealand Civil Defense to take measures to protect the public while weighing the realistic damages that early evacuations and raising Volcanic Alert levels can have on society (e.g., financial impacts of closing a ski resort during ski season). The instructors in the Pilot acted as the Civil Defense officials and the students played the scientists “forecasting” the eruptions.

The pace of the Pilot was very quick, with a simulated day lasting about one minute in real time. Multiple monitoring datasets were “streamed” in real time and presented in several labeled tabs (e.g., Seismic Data or Social Media) on the website interface (Appendix D4). Tongariro Volcanic Complex (e.g., Cole 1978; Hobden, Houghton, Davidson and Weaver 1999) was chosen as the host-volcano; and field trip site. Volcanic activity progressed from a quiescent stage, through small eruptions (i.e., “unrest”) concluding with a very large event, based on the catastrophic 1991 Mt Pinatubo eruptions (e.g., Wolfe and Hoblitt 1996).

During the Pilot, two “pauses” were improvised by the instructors allowing students to take more time to prepare and organise their thoughts and strategies and make educated decisions. Press conferences were simulated when major volcanic activity occurred, for students to communicate their actions, thoughts and decisions to a fictitious “public”. The instructors challenged and guided the students, asked them to justify their decisions and reminded them to consider social or economic impacts of their decisions.

Student data presented in this chapter is annotated with the simulation iteration number and the students’ roles that they played. For example, the quote with the label (Iteration 2, Department of Conservation) indicates the Iteration 2 post-questionnaire data of a student with the role of Department of Conservation Officer. A schematic diagram of the teams with the specific roles is presented in Appendix D3.

5.4.2 The Pace and Preparation

The events that occur in the simulation are meant to replicate the actual eruptive history of Mt. Pinatubo, but at an increased pace as noted above. In the feedback collected from each iteration, the students reported that the simulation "went too fast". In order to ascertain if the pace was detrimental to their learning, we explored how the pace affected the students' behaviours and perceptions.

In the Pilot, the students interviewed said that the pace severely affected their decision-making and their abilities to react to the events occurring.

"Yea, it should go slower. I mean just about when we thought 'there might be an eruption coming', we would think about it. And then, it would just happen... It didn't give us a time to anticipate or think about it" (Pilot, Student 1).

It also affected their ability to communicate: "I found it difficult to get the big picture and be able to communicate it appropriately. I was always worried that there would be another eruption" (Pilot, Student 2).

There were many suggestions from students and instructors on potential ways to decrease the pace and the subsequent "chaos". One instructor suggested slowing it down and having fewer volcanic events: "We [the instructors] felt it could have gone a little slower and had a few less 'events'. We had an awful lot of eruptions, that is what actually happened at Pinatubo" (Pilot, Instructor 1).

Another instructor suggested adding more pauses: "[The students] needed more pauses to convey what was going on. While [streaming] was great to 'keep the pressure' on, there were so many things happening" (Pilot, Instructor 2).

Another suggestion was to add more structure to the activity to allow students to have discrete opportunities to reflect on the events (aiding decision-making) and to write reports. Instructor 1 proposed: “If you had more scheduled [written] reports and then everything stops when you make a report [i.e., engineered pauses]. Then in that time gap, the students could take the time to explain what they’ve done” (Pilot, Instructor 1).

But one of the students questioned whether the simulation should be paused: “I don’t know if the students had the control to pause all the time. It would lessen how stressed we were, but maybe that’s a bad thing. I think we were supposed to be under stress” (Pilot, Student 3).

We observed and noticed from feedback that the students could use more time when an event (i.e., an eruption) occurred, but not in-between (i.e., during normal monitoring tasks). Therefore we kept the streaming time the same for all iterations. Based on these observations and the feedback received we slowed the pace by reducing the number of events (from 30 to 26) and adding in engineered pauses (from 2 to 4) to allow students more time to make quality decisions and communications.

The students from Iteration 1 cited many positive aspects about the pace and how it contributed to their experience. Several students noted the benefits of the fast-paced nature of the simulation stating “It was good having a lot thrown at us” (Iteration 1, Welfare Officer) and “I quite liked the intensity of it” (Iteration 1, Volcanic Section Manager).

Many students associated the high stress (due to the pace) as something that is realistic in a crisis-scenario. One student said: “I thought all the information given to us, thrown at us really, was realistic. I think in [a crisis] situation there is too much information” (Iteration 1, Public Information Officer 2).

However, even at a “slower” pace, many other students continued to struggle to “follow-along”, causing them to miss important events. One student explained this: “Yea, it was really fast. I would go off and talk to one of the [Emergency Management] people and then I would come back and there had been 2 cm of ash and we would be so stuck into what we were doing, that we would miss that” (Iteration 1, Public Information Officer 1).

Students suggested that the quality of their work was affected. For example: “It was so rushed, sometimes, that it was like ‘OK, someone grab a pen and just write something’ ” (Iteration 1, Public Information Officer 2). Others thought the major failing of the simulation was the pace and suggested continuing to “… change the time frame after events” (Iteration 1, Public Information Officer 3).

While it was our intention for the simulation to be fast-paced, we did not want it to be so fast as to inhibit students’ ability of students to react to the scenarios. We wanted to attain a balance of stress so that students can continue to make and communicate decisions. Based on student and instructor suggestions from Iteration 1, we decreased the simulation running time by 24 days, reduced the number of events (from 26 to 24) and increased the number (from 4 to 6) and duration (from ~5-10 minutes to 10-20 minutes) of pauses. Like the iteration before, the pauses were present after important events in order to allow students to perform tasks.

Results from Iterations 2, 3 and 4 indicate that students continue to describe issues “keeping up with the simulation and its demands” (Iteration 2, Field Geologist). When asked specifically how the pace affected their learning and their abilities during the simulation, fewer students (7 of 27) stated they felt they needed more time. The majority (20 of 27), said that “it wasn’t too fast” and the pace was “fine” and that it was beneficial to their overall experience. We observed that students still struggled to communicate with statements such as: “Communication could have been more efficient” (Iteration 3, Section Manager).

Pauses became a respite from the quick pace; moments to reflect, rest and “enjoy”: “[The simulation] flew by. I was shocked, especially after the eruptions started. The pauses were awesome!” (Iteration 2, Field Geologist); “It was always nice to pause when something exciting happened” (Iteration 2, Ash Specialist).

Optimising the pace ultimately rested with assessing how much time students needed to react to an event. For example, one student noted: “The compressed time period was good, but, maybe more time was needed for processing each event. Maybe pause after every event?” (Iteration 2, Meteorologist).

Many students noted “the excitement”: “It kept the adrenaline going and it was exciting” (Iteration 3, Group Controller); “… the feeling of being thrown into the thick of it, added to the overall experience” (Iteration 2, Ministry of Agriculture and Forestry).

Other students noted that they performed “just fine” under the circumstances: “I deal well under pressure and work quickly so the fast pace of the ever-changing activity was easy to keep up with” (Iteration 2, Visual Surveillance); “I thought it was perfect for me, because I was kept thinking the whole time, but not uncomfortably overwhelmed” (Iteration 2, Ministry of Economic Development). We observed that some roles were more busy than others and that there may be a relationship between the students who reported less stress and the roles that they played (along with those responsibilities) in the simulation. These findings are discussed in Section 5.4.3.

There are fundamental concepts that students must bring with them into the simulation (Table 5.6). These building blocks are needed for students to accurately and effectively play their assigned roles and perform the tasks posed to them during the simulation.

Table 5.6: Prior Content Knowledge and Skills Needed for the Simulation

Prior to the simulation, students should be able to….

1. Describe and explain the variety of volcanic hazards associated with different types of volcanism
2. Read and interpret geological and topographical maps
3. List, describe and explain volcanic monitoring data types and interpretation of these data
4. Explain how different monitoring data go together to form a "working model" of what's happening in the volcano
5. Describe the New Zealand Volcanic Alert levels
6. Describe the basic duties of the GeoNet and Emergency Management teams during a crisis.

Items 3-6 in Table 5.6 are specific concepts that students have not covered in previous geology courses. Therefore, we provided additional readings, lectures and exercises that were designed to give students the necessary background concepts. As the complexity of the role-play increased, we matched the preparation materials to the demands of each student's role and responsibilities based on the feedback received. The changes made to the preparation activities are listed in Table 5.7 below.

Table 5.7: History of Preparation Activities for the Volcanic Hazards Simulation

	Pilot	Iteration 1	Iteration 2	Iteration 3	Iteration 4
Time to prepare	Entire day prior, (on field trip)	Activities posted 1 week prior; online	Entire day prior, (on field trip)	Entire day prior (on field trip)	Activities posted 1 week prior; online
Sim. was embedded in:	Embedded in Field Course	Embedded in Lecture course	Embedded in Field Course	Embedded in Field Course	Embedded in Lecture Course
Preparation Activities	Hazards Map Activity (Basic) Lectures	Hazards Map Activity (More detailed) Lectures (course based)	Hazards Map Activity Lectures	Hazards Map Activity Lectures Science Communication Best Practices	Hazards Map Activity (half of the class) Lectures (course-based) Science Communication Best Practices
Simulation Instructions	Basic	More Detailed	Complex	Complex	Complex
Role Specific	N/A	Very basic Students had to research their own online	Basic descriptions of roles	Role Profiles	Role Profiles
Student Library	No	No	Yes, basic	Yes, detailed	Yes, detailed
Flow of Information Maps	No	No	No	Yes	Yes

In the Pilot, students attended a week-long volcanology field course. The entire day prior, the students worked on creating a detailed volcanic hazards map for the Tongariro Volcanic Complex with assistance from given literature (Hazards Map Activity). This activity was designed to give students the needed familiarisation to the region, community, place names, landscape and geologic history of the volcano. They were also required to designate and explain hazard zones on their maps with relevance to the New Zealand Volcanic Alert Levels (GeoNet 2011). The Hazards Map activity was used as the main preparation activity for all iterations.

In addition to the Hazards Map activity, students were given basic instructions on what to do during the simulation. In the Pilot and Iteration 1, the instructions were communicated in person via a short lecture prior to the activity. These instructions became progressively more complex as the activity itself became more complex. A detailed hand out was developed and given to students for and after Iteration 2.

Feedback from instructors and students in the Pilot indicated that much more “background” was required to help students communicate better and perform the simulation tasks. One instructor explained: “I think at the start, the student’s needed some more general background to [volcanic] hazards and to the [geologic background of the] volcano. If I had been a real Press [member], I would have wondered what this is all about. I would want some type of background from the geologists on what could happen at the volcano, in the beginning of the “unrest”. And then they could use the hazard map to explain it. There was a need for more background” (Pilot, Instructor 1). A student agreed: “I had to communicate with Civil Defense. I should have had more information. It was all kind of scattered. I would get asked questions and had no idea how to answer them. I didn’t know how to even write the reports, at all” (Pilot, Student 3).

In Iteration 1, the students were assigned roles. They were expected to research their job titles and positions online. We provided web addresses and posted basic Emergency Management literature on a shared website for the students to read. The Public Information Management students were also required to research the New Zealand Volcanic Alert levels and write media releases to the public explaining the science and impacts of an Alert Level change from 1 to 2.

As a result of providing preparation readings and instructive materials to the students, the preparation-related feedback from Iteration 1 improved from the Pilot. After the simulation, several students expressed their interest with what they researched their discovered about and explained how their research assisted in their responsibilities. Examples of improvement included better quality and efficiency in the writing of media releases and general awareness of what the roles and teams were intended to do during the crisis. However, the majority of students continued to exhibit specific and general preparedness that affected their abilities to achieve the learning outcomes. For example, students were unaware of the importance and sensitivity of Alert Levels (i.e., the general consequences of those actions) and some students could not perform the main tasks to which they were assigned (e.g., the ash specialist could not draw accurate ash maps; and the infrastructure manager was not aware of the main transport conduits of the North Island of New Zealand).

In order to improve preparedness and match the preparation readings to the specific roles and responsibilities, we created a Student Library available prior to the simulation (See Appendix D6 for the full bibliography). In practice, the Library explicitly shows students what they should read. When prompted in the post-questionnaire, students noted that literature from the Student Library helped them to prepare more than the other preparation activities. For example: "... the literature was most helpful because it gave direct notifications of what we were supposed to look for" (Iteration 2, Volcano Geophysicist); and: "I think the literature was the most helpful because it provided us with the necessary background information for our roles" (Iteration 3, Department of Conservation).

The other preparation activities (i.e., lectures and Hazards Map Activity) also helped students develop expectations for their roles and tasks: "Yes, everything helped me to prepare for what was expected on the day. The most helpful was looking at the media releases in the literature and to see the format and the wording" (Iteration 3, Public Information Officer); "I felt very prepared. All my readings and researching beforehand really helped as I then had a better understanding of the team dynamics and the science" (Iteration 3, Volcanic Section Manager).

Some criticisms of the later iterations were related to the specificity of the roles and it was suggested it must be clearer what should be read for specific roles and what that role explicitly does during the simulation. To better describe the skills needed and to better communicate team structure details to the students, we developed Role Profiles. These were implemented in Iteration 3 and 4 and were modelled after the Civil Defense and Emergency Management Role Maps used for professionals (Ministry of Civil Defence and Emergency Management 2013). Each Role Profile includes the job's purpose, duties, to whom they report to, whom they are responsible for, and the key competencies (i.e., skills) needed. One of the Iteration 4 students noted how the Role Profiles helped: "The description of the role was most helpful, [I had a] clear understanding of my role, responsibilities and whom I needed to communicate with" (Iteration 4, Duty Manager).

Despite all of the preparation activities, some of the Iteration 4 students appeared to be less equipped during the simulation. The Pilot, Iteration 2 and 3 were run during a field trip. The field trips were designed to allow students to get into the depth of the topics needed for the simulation through lectures and fieldwork. We observed, generally, that students had the required content knowledge needed to carry out the tasks in these iterations.

One of the students responded, saying: "I felt about 80% prepared for the simulation… the whole week in the field was helpful to get a better idea of size and scale [of the eruptions]" (Iteration 2, Ministry of Health).

In contrast, Iteration 1 and 4 simulations were used as summative, “capstone” activities for physical volcanology, hazards and disasters courses. The students from Iteration 1 did not appear to struggle with the geologic content knowledge needed, but we notably observed that several students in Iteration 4 were not as prepared. Some of the students exhibited less geologic content knowledge (than was expected and needed) and we observed that this brought down the collective abilities of the GNS team.

One student misjudged the importance of their role: “I felt my job was very basic, so I may have under rated it a bit” (Iteration 4, Visual Surveillance). This role is very crucial for observing the changing activity and identifying the style of eruptions at the volcano. But this student lacked important geologic knowledge: “I wanted to know more of an overview of volcanic eruption styles and eruption types” (Iteration 4, Visual Surveillance).

The team leader of GNS (the Volcanic Section Manager) also exhibited less than necessary content knowledge. This was evident when a team was discussing possible outcomes of the volcanic unrest needed to look-up the definition of “Plinian” (i.e., a classification term to describe a very large-scale eruption that students are introduced to in previous courses). These students’ lack of knowledge contributed to the team’s inability to create a working hypothesis of the volcanic activity and an instructor was required to step in and help assist the group. In the end, the team did achieve a considered success and their teamwork and communications skills were more than adequate (i.e., communiqués became more efficient as the time passed and major decisions were made). However, we observed that the poorer content knowledge inhibited sophisticated problem-solving and synthesis skills needed to support the team’s complex reasoning.

Several students admitted to not preparing for the simulation whatsoever. Only 8 of 26 students on the field trip for Iteration 2 actually read the documents in a meaningful way. In Iteration 3 and 4 students confessed: “I could have made more use of the library beforehand” (Iteration 3, Visual Surveillance); “I didn’t read anything prior and I should have allocated more time to readings and understanding the role that a geophysicist plays in the GNS team” (Iteration 4, Volcano Geophysicist).

Additionally, despite the preparation activities provided, some students felt that there was “no way” to prepare for the simulation. “I don’t think there was any way that I could have been fully prepared” (Iteration 3, Group Controller); “No [I didn’t feel prepared], but the information given gives us a good background on what’s needed to be done. This job would be hard to prepare for” (Iteration 4, Crisis Information Manager).

Some students did not anticipate the level of stress they would encounter: “Yes the literature, lectures all helped. I felt about as prepared as I could have been (given my lack of experience in these situations), although I did not anticipate the level of activity/stress/quickness of everything” (Iteration 2, Volcanic Section Manager).

5.4.3 Role-play: Roles and Teams

Generally, the simulation proved to be a very positive experience for students and we find that this is closely linked to the roles and the authenticity of the simulation. One student recalled the benefits of the role-play itself: “I think it’s a really good simulation. I think you get put in a position to make super important decisions and I think with having all the different teams and having to communicate with them in other rooms. It really adds to the realistic aspects of it.” (Iteration 1, Group Controller).

Many students thought that playing geoscience jobs and potential careers was a great asset: “It is also nice to kind of see a real life geology career” (Iteration 2, Ash Specialist); “Yes [my role] is a position that I would like to have later on in life…” (Iteration 2, Geochemist). These opportunities to take on the responsibilities of real life professions are rarely found in traditional educational activities.

Other students noted that they enjoyed taking on roles that were new to them: “I am from ‘The City’, so playing the Minister of Agriculture was outside of my area… It was interesting to play the role. Because it was something different, something new, something interesting.” (Iteration 1, Minister of Agriculture). This allowed them to explore new topics and gain new perspectives: “... it was different and it opened my eyes to a different perspective” (Iteration 2, Ministry of Transport).

In the Pilot, there were no pre-defined roles. We observed that in order to cope with the stress, the students self-organized into roles that included: the “Data” people and the “Press” people, while the instructors and tutors comprised the remaining stakeholders (e.g., the Mayor of the nearby town, the Emergency Management Director, the Department of Conservation). Prior to students self-organizing, the group was visibly unorganized and inefficient. Students did not have defined tasks, responsibilities and therefore students did not lead or divide the workload to accomplish the tasks. The simulation was in danger of getting off track and the instructors were required to intervene to help students delegate tasks and responsibilities. These observations were the primary purpose to introduce structured role-play.

Role-play related feedback collected from all iterations was very positive. The students indicated that "individual roles were generally very effective" (Iteration 3, Crisis Information Manager). The positive aspects mentioned included:

1. Individual responsibilities: "I loved that we had roles… everyone had roles, they knew what they were supposed to be doing, like where to draw the line between you and your mate" (Iteration 1, Welfare Officer); and dividing the workload: "We were good at dividing up the tasks and finishing up our own responsibilities" (Iteration 2, Ministry of Health);

2. Role immersion: "it was good having different teams and everyone having a different role so that you could really, like, get into one aspect" (Iteration 1, Volcano geophysicist); and

3. Helping students to focus and stay on task: "Yes playing roles was helpful because we could focus just on that job and understand it" (Iteration 2, Public Information Officer).

Beginning in Iteration 1, we observed that some roles were more "pivotal" than others (i.e., those that greatly affected the success of the simulation). Pivotal roles were in the position of leadership (Group Controller, Volcanic Section Manager) and the communication links or liaisons between the teams (Public Information Managers, Infrastructure Manager and the Duty Manager). These roles made major decisions and acted as the bridges for information to flow efficiently between the teams. These tasks are crucial working parts of the simulation.

In the first two iterations, students reported there was a discrepancy between the workload and "importance" of some of the roles. In Iteration 1, this was noticeable between students who had significant responsibility, such as the team leaders, and those who did not have a lot of responsibility. “I didn’t feel that I had as much responsibility… I didn’t feel like in as much pressure, because, I only had one thing to worry about, to concentrate on. Where like, the Evacuations people had to worry about everything” (Iteration 1, Infrastructure 1). Another student noted: “[the simulation] wasn’t really that hard for me, but I didn’t feel that my personal role involved very difficult decisions” (Iteration 2, Ministry of Transport).

The team leaders had many responsibilities. One team leader recalled all the tasks that he/she needed to perform: “[I had to] make final decisions, to hold meetings and synthesize the various datasets, to keep the team organized and running smoothly, to communicate with the media and the public officials” (Iteration 2, Volcanic Section Manager).

Students became aware of this discrepancy and to make work more efficient and accomplish their collective goals, they resorted to task (i.e., job) sharing. In Iteration 1, job sharing was more prevalent as the Public Information Officers were placed in a separate team with no specified roles. Therefore, incoming tasks were divided up and shared among the members of the team to maximize efficiency: “As the Alert Levels were raised, a lot of people didn’t stick to their roles [in the Public Information team] because there was so much going on. So we helped each other out, depending on where the action was” (Iteration 1, Public Information Officer 2) or “… in the end we all kind of overlapped and all had to liaise with each other to save time” (Iteration 1, Public Information Officer 4).

In later iterations job sharing continued and was shown to improve teamwork: “Job sharing was smooth, everyone helped each other” (Iteration 4, Public Information Officer).

We observed that the students assigned to pivotal roles became overwhelmed during the simulations. In Iteration 1, the team leader of the Emergency Management team was very overwhelmed with their responsibilities:

> "I was the Group Controller… There was a whole lot of information. I was worried about how I should be handling this information… It was OK at the start and there were little bits of information coming through. But then all at once, it was just too much and I didn't know what to do. I just got a little lost {student laughs}. And then at the end, like we all started organizing ourselves a bit more… as long as I spoke to one person at a time, I could make a decision. It was much more organized towards the end… but I couldn't really comprehend it all at the start… It was too much information at once at times; I didn't know how to deal with it." (Iteration 1, Group Controller)

A primary source of stress was the amount of information that needed to be processed by leader roles. This occurred in both teams, across the iterations. For example: "There were six people yelling [information] to [the team leader] and he/she would write it down, but I don't think there was enough time for him/her to react to what was happening" (Iteration 3, Field Geologist).

We concluded that there were too many tasks for some roles to carry out simultaneously. Following similar findings in Iteration 2, a Duty Manager role was implemented in Iterations 3 and 4, comparable to a similar role used in the Civil Defense and GNS structure (Ministry of Civil Defence and Emergency Management 2002). This new role manages the staff and controls the information going to the Group Controller. They share the responsibilities previously assigned to the Group Controller, thereby decreasing the overall stress of this position.

The Duty Manager role was deemed invaluable to the team leader: "I would have literally died without the Duty Manager, [they were] very, very necessary" (Iteration 3, Group Controller). The Public Information Officers were responsible for the efficient and accurate passing of information between the teams. These pivotal roles were observed to be more overwhelming than other roles.

The Crisis Information Manager (added in Iteration 3 and 4), who was responsible for monitoring the Social Media feed in the Emergency Management team noted how over burdened he/she was: “I got overwhelmed in the middle of the simulation, because I struggled with keeping up with the amount of [information] that I had to record (from the social feed)” (Iteration 3, Crisis Information Manager).

To assign students to roles matched to their personality and skills, we designed and implemented Role Assignment Questionnaires (see Appendix D5). This was deemed necessary because we observed that when students were in roles they did not feel capable of doing become too overwhelmed and debilitated by the simulation. The questionnaires were given out prior to the simulation in an attempt to gauge their abilities (e.g., self-reported capabilities with maths, communication, writing and leadership) and their interests (e.g., geology, emergency management; i.e., career-matching). However, instructors admitted that matching students to the right roles was difficult and could be incorrect based on how the students responded. The main criteria of interest in the Role Questionnaire were their self-reported abilities to lead, perform quantitative tasks and communicate (i.e., qualities of the pivotal roles).

One element of the role-play that we did not anticipate would have a negative impact was the level to which students became immersed in the simulation. The drawback to role immersion is that some students became introspective and “put their blinders on”: “It helped me learn more about my specific role, but I did not know what the others did” (Iteration 2, Volcano

Geophysicist); “I did well at focusing on my specific role, but I didn’t do well at thinking about other people’s roles” (Iteration 4, Department of Conservation).

The data suggests that many students noted the phenomena of role immersion (i.e., getting into the learning experience; e.g., Lessiter, Freeman, Keogh and Davidoff 2001) and role identification (i.e., feeling that they relate to that role; sense of belonging and commitment e.g., Handley et al. 2006). For example: “… it was easy to slip into the role for the game” (Iteration 3, Department of Conservation); “People got really into their roles” (Iteration 2, Public Information Officer); [My role] just seemed to fit naturally with me and I sort of eased my way in and “got stuck right in”, as the activity increased” (Iteration 2, Visual Surveillance). Conversely, some students reported an ability to see the bigger picture and how their role fit into it: “It was great for understanding how each small role is vital to the bigger picture understanding and management” (Iteration 2, Meteorologist).

We also observed that some students became so involved with their tasks that they became “closed-off” to the other role-players. One of the students in Iteration 2 summarized this issue well: “I think sometimes that if you get really into your role, you think ‘Oh yea, like everything depends on me and my role’, rather than looking about at what everyone else is doing, the effects of their roles and what they are monitoring” (Iteration 1, Gas Geochemist). While, we wished to retain the positive aspects of role immersion, there were efforts in the later iterations to emphasize the team structure and best practices of teamwork.

Effective teamwork skills are fundamental to the success of the simulation. The two teams (Emergency Management and GeoNet) have large student numbers (ranging from 8 to 20 members depending on the class size) and rely on all members performing optimally. As previously mentioned, the Pilot had no defined role structure or teams to speak of. In the iterations that followed, the students exhibited both positive and negative team dynamics.

There were two, frequently mentioned positive teamwork aspects including: the students' abilities to "compile everyone's thoughts" (Iteration 2, Group Controller) and listen to one another "… we were all heard and we all listened to one another" (Iteration 2, Public Information Officer), "We were attentive to each other" (Iteration 2, Ash Specialist).

Students also noted that good teamwork required supporting and being supported by the team leader: "We listened to the [Group] Controller and went with his/her calls" (Iteration 2, Public Information Officer); "We had a definitive leader in our team" (Iteration 2, Gas geochemist); "It was a real collaboration, the leader didn't just override us, he/she considered our opinions" (Iteration 2, Public Information Officer); "I think that within the team, communication was fantastic. Everyone was really good. Everyone just jumped up and talked to each other and said 'What are we going to do?" (Iteration 1, Welfare Officer).

Others disagreed saying that students frequently "talked over people" and exhibited poor listening skills (e.g., "not attentively listening to other people" (Iteration 2, Volcanic Section Manager)). For example: "I don't think the communication between our team was good. There were times when people like me didn't get to talk at all, because everyone was talking" (Iteration 1, Infrastructure). These negative behaviours caused some students to lose focus: "I could not concentrate well with lots of stressful shouting around me and loud noises" (Iteration 2, Department of Conservation). This led to an increased difficulty to make decisions: "There were intense points when everyone was talking *all* at the *same* time. This obviously made it impossible to think and to make good decisions" (Iteration 2, Evacuations).

Negative group dynamics continued for some of the teams in later iterations and this was mostly due to strong or overbearing personalities of individual students. The team leaders were chosen for their self-reported abilities of teamwork, leadership and confidence with public speaking. Some of the leader students, however, exhibited domineering behaviour. For example: “I wasn’t able to [speak at the press conferences] because of my “Boss”, who wanted to be in the spotlight the entire time” (Iteration 3, Volcano geophysicist).

Other issues arose during team discussions: “Initially, I struggled slightly in discussion involvement as there were several more dominant team members” (Iteration 4, Infrastructure). Iteration 2 and 4 had students assigned in the Volcanic Section Manager role (team leader) who we observed to behave negatively towards their fellow team members. The leader from Iteration 4 abruptly dismissed dialogue with several team members and exclaimed “I’m way too busy for that” (Iteration 4, Video Transcript). This sort of behaviour was observed to be linked to times of stress during the simulation.

Some students reported not favouring teamwork in general: “I think I would be pretty good at dealing with people, but then again, it puts me off a bit because I’d have to work in a team, because I usually like go off on my own and make my own decisions. It’s just too difficult to encompass everyone’s thoughts” (Iteration 2, Public Information Officer 5).

5.4.4 Communication

From the onset of development, we wanted the students to learn the importance of communication in a crisis scenario. In the Pilot, we qualitatively observed improvement in the students' communication skills over the course of the simulation.

One instructor reflected on this: "I think the really good thing was to see [the students] improve over the course of the exercise and the importance of communication and delegation. At the start, it was chaos, but as they got into it, they got good at passing the information to whom it was needed" (Pilot, Instructor 1). Students also reflected on what they learned and noted the importance of communication: "The main thing we learned in the simulation was about communication. Like the different forms of communication, because it was really chaotic in the beginning. We learned who we needed to communicate with" (Pilot, Student 4).

In the subsequent iterations, more effort was made to give students communication "best practices" so that they might implement them earlier and better during the simulation. We discuss herein the *content* of the communications and the inter-team communications (i.e., between teams, refer to Figure 5.3). It is relevant to reiterate that a major goal is for students to learn about communicating in teams and in general. Therefore, difficulties, successes and confusion are all relevant to the learning experience but, as with the pace, not to the point of incapacity.

The information content was consistently mentioned by students in all the iterations. Iteration 1 students made suggestions that this was a barrier to the overall success: "Yea, so the communication coming into the room. Just tell us simply ya know, we don't need the details of the magnitude of every earthquake that happens on the Volcano. We just need to know what we need to know. Just the data stuff." (Iteration 1, Field Geologist).

Students from other iterations also had issues with the content:

1. Difficulties determining the "important" information: "We didn't know what the information was important and what we needed to pass along" (Iteration 2, Public Information Officer 2); "As the information became readily available, I tried to assess what was most important" (Iteration 4, Volcanic Section Manager); "It was difficult to determine that scientific data was more important [to communicate]" (Iteration 2, Volcano Geophysicist); and

2. How much information to pass on: "I was probably giving too much unneeded [information] to people who didn't need to know" (Iteration 2, Ministry of Agriculture and Forestry); "Some people told me way more than I needed to know and some not enough" (Iteration 3, Group Controller).

As the learning goals were to communicate well, it became evident that distilling what is considered "good communication" into "best practices" was required. Iteration 2 students responded with their own ideas of what good communication entails. Phrases used by the students included: "accurately", "clearly", "professionally", "timely", "efficiently", "confidently", "organised" communication.

Some criticisms included jargon use: "Our communications were too scientific for the public" (Iteration 2, Meteorologist). Communication best practices were distilled into a set of advice to students prior to Iterations 3 and 4 and Rubrics that instructors used to provide feedback to the students during and after the simulation. Table 5.8 below refers to best practice communication with the public (to be used at the press conferences).

Table 5.8: Communication Best Practices with the Public – Excerpts* from Best Practices, used in Iteration 3 and 4

1. Who is your audience? What background in science does your audience have? Are there common misconceptions they may hold? Is there an aspect of your science that is sensitive, or controversial to them? Will they respect your opinion/practices? What words should you use?
2. Providing Context for the audience: Explaining to the audience the IMPORTANCE of your work is one of the most powerful (and often missed) points that a communicator should address. If you start to explain a complicated process and do not provide the 'who cares' and 'how does that effect me' statements, your audience will not be motivated to listen to you.
3. Misconceptions and Arrogance Avoid phrases like "obviously" and "of course you will know this". Your audience does not lack intelligence – they simply lack expertise in your area. They may hold misconceptions as well (things that they think to be true, but are not). Be patient and open.
4. Jargon-appropriate communication: Jargon is a word or phrase that is specialized. Science jargon is only appropriate when describing something to a colleague within your discipline. As a science student, you are asked by your professors to learn new words (jargon) that are used to explain/describe exactly what you mean. This is important for colleague-communication, but is rarely appropriate in any other situation.
5. Use of Emotions: Conveying emotional aspects of your science (when appropriate) will help you connect with the public. If your findings have affect human beings, then showing emotions is healthy and people respond to this.
6. The great 'Uncertainty': It is important to be clear about how 'certain' you are about your findings. Also to convey that 'this method'; or 'this type of science' may have certain caveats… The public may WANT you to have a firm answer – when in reality this is NOT realistic.

* These best practices are derived from a handout given to the students and as excerpts from a lecture to accompany it.

The second component of communication training was teaching students about the pathways of communication. The students wanted to start with "rules" of communication: "It would be good to establish rules about communication" (Iteration 1, Public Information Officer 3). Iteration 1 had three teams and we provided them with a simplistic flow chart for how those teams should communicate (the flow chart consisted of the three teams, with double-sided arrows going between all three components). However, students wanted to know more about the "boundaries of communication": "It gave us a sense that we should all be effectively communicating and that the teams should communicate with each other, but we didn't know the boundaries..." (Iteration 1, Gas Geochemist).

A communications "bottleneck" occurred several times in Iterations 1 and 2 as too much information was required to flow through the team leaders and the Public Information Officers (i.e., the pivotal roles). When these role-players were stressed, the communication broke down. For example, in Iteration 1: "The communication between us and the other geologists was hard because we had to communicate through [the team leader]. And [the team leader] was too busy with everything sometimes to relay it" (Iteration 1, Field Geologist).

During Iteration 1, crucial information, such as the status of the Volcanic Alert levels, was not received by the Emergency Management team: "We couldn't get data from the GeoNet team, so that made it quite difficult. And then we realised that we hadn't heard of [the Alert Level being raised] and that communication was absolutely no good" (Iteration 1, Ministry of Health).

In Iteration 2, the Public Information Officers became overloaded as they passed information between teams through media releases and verbal updates: "It seemed frustrating to me to be the liaison between the two groups that were so busy and stressed" (Iteration 2, Public Information Officer 3); "My responsibility was ensuring communication between [Emergency Management] and GeoNet and the Public was effective. I spent most of my time going back and forth between GeoNet and [Emergency Management]" (Iteration 2, Public Information Officer 1).

In response to this feedback two roles were added to Iterations 3 and 4 (Crisis Information Manager and Duty Manager) to create additional communication pathways and relieve the collective stress outlined in the previous sections. We also assigned more than one student to the Public Information Officer role for each team to lessen the communications workload.

To further improve the communication pathways, we created Flow of Information Diagrams (Appendix D3.1 and D3.2) that were given to students in Iterations 3 and 4. The practicalities of the diagrams were explained during preparatory activities and the beginning tasks of the simulation. However, this did not produce the desired student behaviour outcomes: “I didn’t really know how the flow of information would work” (Iteration 3, Infrastructure Manager); “I wasn’t really sure of how I was meant to liaise with the other team.” (Iteration 4, Public Information Officer 1).

It was very common that information was sent from the GeoNet team, but often not as quickly as the Emergency Managers wanted/needed: “[The Emergency Management] team didn’t get stuff from the scientists fast enough” (Iteration 3, Infrastructure). The instructors concurred with this observation.

In addition to the Flow of Information Diagrams, we provided students with colleague (intra-team) communication “best practices” (Table 5.9 below) to discuss and practice during preparation activities for Iteration 3 and 4. This resulted in fewer negative communication behaviours within the teams, such as over-talking. For example: “My team respected each other’s specialities and did a good job including each other in discussions” (Iteration 3, Infrastructure Manager) and, “we talked a lot and well within our group” (Iteration 4, Department of Conservation).

Good communication contributed to better teamwork: “We all provided our individual ideas of events, contributing to all aspects” (Iteration 4, Infrastructure Manager); “Our team has excellent collaboration and good discussions” (Iteration 4, Duty Manager).

Table 5.9: Team Communication - Excerpts from Instructions and Science Communication Best Practices

Communication Rules: Respect the **group organization** and your roles. The Section Manager and Group Controller are "in charge" but your group must work democratically to achieve the best solutions. Refer to **Flow of Information** documents at the end of this packet.
The simulation activity requires you to use: **TEAMWORK**: the ability to work effectively as both a team leader and a team member. **COMMUNICATION**: the ability to communicate information, arguments and analyses effectively. **CRITICAL THINKING**: the ability to analyze issues logically, consider different options and viewpoints and make informed decisions.
Excellent Collaboration Skills consists of: brainstorming, sharing, debating and diplomacy
Speaking with Colleagues: Some useful best practices include: • Use **terse** [brief, to the point], summative statements, • Be **explicit** [exact, mindful, jargon-appropriate] about the concepts you discuss, • **Cite** previous studies, • Use **numbers** and **terms** to quantify your findings and • Be **transparent** about the limitations of your findings [Is this work preliminary?]
Communication with other Professionals: Talking to other scientists outside of your area of expertise can be difficult. The key to understanding each other is getting over jargon-issues. Scientific processes can transfer between disciplines, but language and jargon does not. They will not be familiar with the terms you use. So be mindful of that.

In spite of this support, there were still negative aspects of the students' teamwork abilities involving group discussions and decisions. Students stated that "it was difficult coming to a final conclusion" (Iteration 4, Public Information Officer 1). As a result, students resorted to splitting: "Sometimes we broke down into several small groups talking and not full group discussions when we were talking about something that required everyone's input" (Iteration 4, Welfare Officer). "[I had] difficulty communicating with some team members who did not contribute to the group effort, or respond to the team's concerns" (Iteration 3, Crisis Information Manager).

The simulation is an experiential learning experience; it requires the students to practice these skills, receive immediate feedback and learn how to communicate effectively in different scenarios. Students from all the iterations struggled, but eventually successfully identified what information is important, to pass it to the other team: “Communication became better as we went and we only passed on the key facts” (Iteration 2, Field Geologist); “I relayed only the ‘need-to-know’ information” (Iteration 3, Volcano geophysicist).

In summary, negative and positive team behaviours revolved around the strengths and weaknesses of the team leaders and team member’s abilities to communicate with one another. As teamwork and communication skills are fundamental to the simulation design, we observed that the simulation forces students to use these skills and work through any issues that arise during the role-play. There are very few opportunities in university degree programmes that simulate and exemplify the real life tensions and importance of these transferable skills.

5.4.5 Summary of Results

The above observations, student interviews and questionnaire data, lead to the conclusion that:

Pace and Preparation:

- The simulation pace was too fast for students to accomplish the learning goals. Reducing the simulation pace (primarily by reducing the number of volcanic events, increasing the length and number of pauses) allowed the students more time to communicate and make decisions. Students' self-reported abilities (individually and as a team) to cope and manage the tasks was substantially improved. This resulted in a qualitatively more successful simulation.
- Observations and interview data indicates that students did not possess the necessary content knowledge and skills necessary to perform well during the simulation. Newly implemented detailed preparation activities provided students the necessary background required for the simulation. Content knowledge (via Lectures, Student Library), role preparation (via Role Profiles and Student Library) and instructions allowed students to develop expectations and increase preparedness. Students who displayed (and reported) inadequate geoscience background did appear to struggle and reduce the collective reasoning abilities of the team, inhibiting decision-making and hypothesizing. Therefore, increasing detailed and directed preparation improved their overall success of meeting the learning goals.

Roles and Teams:

- The Pilot was chaotic and unorganized, making it difficult for the students to perform efficiently and effectively. Introducing specific roles, with defined responsibilities, allows each student to focus on their tasks and contribute to the team and collective success.
- Assigning students to roles befitted to their interests and capabilities (using a Role Questionnaire) resulted in students identifying more closely with the roles and operating as successful decision-makers, data-interpreters or communicators. Role assignment is not exact, but these questionnaires allow avoidance of significant personality mismatches.
- We identified pivotal roles within the simulation. These roles were carefully assigned in Iteration 3 and 4, resulting in observed and self-reported better team cohesion and communication quality which are major learning goals.

Communication:

- Several components of communication are of great importance to the simulation success:
    - A. communication pathways;
    - B. efficiency of communication; and
    - C. communication best practices.
- Students adapted their skills and learned from challenges in the beginning of the simulations to improve communication. They consistently identified communication as the most important aspect of the Volcanic Hazards Simulation.

5.5 DISCUSSION

This study indicates that iterative and balanced changes to the design variables of a complex simulation result in an optimal, challenging learning experience. We identified three crucial design aspects from observations, interviews and questionnaire data: 1. overall activity pace of the activity and the detail and involvement of preparation activities; 2. controlling the roles and team structure; and 3. best practices of individual and team communication. Modifying these components improved the observed successes of the simulation. The results are discussed herein with reference to cognitive load theory, theories of task and social motivation and team-based organizational theories.

5.5.1 Individual and Collective Cognitive Load

The Volcanic Hazards Simulation consisted of almost entirely complex, interconnected tasks. For example, a team reacts to and discusses a volcanic event:

- The team must discuss all of the potential impacts that a given event might have on the community concerned.
- They must then decide which aspects are priorities.
- Information must be gathered from all the affected sectors and it must be weighed and judged accordingly.
- A student must then transmit all these facts (understand what and why these facts are relevant) in an appropriately written media release to the public.

Each of these discrete aspects requires effective use of the students' skills (Bloom et al. 1956; Isaacs 1996; Lord and Baviskar 2007) to accomplish the overall goal (e.g., *weighing* and *judging* the impacts of a volcanic event, and *assessing* which is of greater priority).

When the processing capacity of a student's working memory is exceeded, their cognitive system might become overloaded by the high number of interacting elements needed to be processed (e.g., Paas, Renkl and Sweller 2003). This manifests itself as incapacity to react to the situation effectively (i.e., self-reported or observed qualities of being ‘overwhelmed’ or ‘stressed out’).

Complex tasks are typical of the simulation and are repeated many times. Students that were new to the concepts overloaded their working memory with any one of the discrete aspects of the complex task (e.g., Section 5.4.3, Iteration 1 Group Controller and Iteration 3 Crisis Information Manager). In order to allow students to take on challenging, complex tasks, we manipulated specific design components to reduce the individual and collective cognitive load: the pace and preparation activities (Section 5.4.2) and the number of and assignment of pivotal roles (Section 5.4.3).

The pace of the simulation was defined by the rate of the streaming data, the number and length of pauses with relation to the tasks (e.g., volcanic eruptive events) that the students were presented with and the number of events. The rate of the streaming data was essentially maintained as we observed that the monitoring tasks did not overload students, until an ‘event’ occurred. The number and length of pauses were increased to allow students more time to complete a task. Lastly, the number of volcanic events was decreased and pauses were engineered to occur directly after the major events to provide time for adequate reasoning (Section 5.4.2).

Cognitive load theory also suggests that when learning new material, an individual’s working memory can store seven elements, but can manipulate only two to four elements at any given time (Sweller, Van Merriënboer and Paas 1998; Kirschner, Kester and Corbalan 2011). There were times in the simulation when individual students were required to perform multiple tasks at once and these times correlated to students being visibly overwhelmed (e.g., Iteration 1, Group

Controller; Pivotal roles). By increasing the time that students were given to carry out the tasks, we decreased the cognitive load of the individual student and the collective cognitive load of the team (Section 5.4.4; Iterations 3 and 4, Paragraph 10).

In the early iterations of development, we observed that some students did not possess the necessary content and skills-based knowledge needed for the simulation. By increasing the students' prior knowledge through preparation activities, we observed fewer examples of cognitive overload. Students who possessed (and reported) inadequate geoscience background also appeared to bring down the collective reasoning abilities of the team inhibiting decision-making and hypothesizing (Iteration 4; the team leader and group member's lack of basic volcanology concept knowledge). Therefore, we inferred that preparation was a crucial aspect of the overall pedagogy, in supporting all of the learning goals.

Students who did the preparatory activities reported feeling prepared in later iterations: (e.g., "I felt very prepared. All my readings and researching beforehand really helped as I then had a better understanding of the team dynamics and the science" (Iteration 3, Volcanic Section Manager). Further research is needed on how most effectively engage students with the preparation materials to ensure good integration in students' schemata.

Repeating a task theoretically commits the new task information (i.e., context, procedure, etc.) to long-term memory (Ericsson and Lehmann 1996), hence freeing up cognitive resources to focus on other aspects of the task (e.g., the quality of the task). As students became more familiar with the skills and task requirements during the early parts of the simulation, the level of sophistication and outcome of tasks improved (e.g., better quality of written communications and more efficient decision-making).

Team learning can be more effective when structured and scripted (e.g., Dillenbourg 2002). Division of the workload, job sharing and adding more students assigned to pivotal roles reduced individual cognitive load. Additionally, clear, transparent boundaries between roles allowed students to focus on their tasks and make complex tasks into smaller, discrete tasks manageable by many, rather than one person. Interdependent tasks (where team members relied on one another to complete a task or outcome; Wageman 2000) required a collaborative approach to complete complex tasks during the simulation (Wageman 1995; Rousseau, Aubé and Savoie 2006).

Assigning students with positive leadership skills and or well-established geological schema to these pivotal roles produced teams that delegated tasks more efficiently (e.g., Iteration 3 Group Controller, Iteration 4 Duty Manager) and effectively so that interconnectivity of discrete tasks became less burdensome. Improving the students' awareness of what each role is responsible for and whom they should interact with, reduced the time (and subsequently, the cognitive load) spent in the beginning acclimatising and allowed them the freedom to tackle the tasks at hand. The Duty Manager role was instrumental in lowering the total number and complexity of tasks that the Group Controller was responsible for, and is evident comparing Iteration 1 Group Controller to Iteration 3 Group Controller (Section 5.4.3).

5.5.2 Task Motivation and Social Interactions

Research shows that humans enjoy facing, and are motivated by, challenging tasks (e.g., Vygotsky's Zone of Proximal Development theory (1978); or flow theory Csikszentmihalyi, Abuhamdeh and Nakamura (2005)). The motivation to engage in a given task is individually defined and based on several criteria that control what 'importance' a person will assign to a given task (e.g., Eccles and Wigfield 2002). The design components that were most concerned with aspects of motivation were the perceived challenge and authenticity of the tasks (Section 5.4.3, students reported positive immersive experiences), roles and social interactions. We controlled for these components by: 1. increasing preparedness; and 2. matching capabilities via role assignment.

Preparation activities served two motivational purposes: 1. to further improve a student's self-efficacy; and 2. to foster positive expectations before participating in the simulation. By providing detailed preparation activities the students became familiar with protocols and skills needed in the simulation. Student feedback also indicated that the students immersed themselves into these roles by researching them prior and 'getting into it' during the simulation. The roles were progressively more specialised (with customized readings, skill sets and responsibilities) with each iteration. Formative assessment and customized learning experiences are less feasible in classrooms with larger student numbers (McKeachie 1980; Gold and Haigh 1992; Gibbs, Lucas and Simonite 1996). This simulation is novel and exceptional as an attempt to accommodate the aspirations of more than twenty students at the same time.

The first two iterations highlighted the fundamental importance of assigning students to the right roles. We show here that assigning students to roles tailored to their interests and capabilities (using a Role Questionnaire), resulted in students being more likely to identify with the role and to operate more successfully. This aspect of overcoming challenges encourages a sense of self-efficacy and autonomy in the students, who may choose to continue to take on increasing challenges in the future (Kuhl and Blankenship 1979).

The students in our learning activity were assigned to roles based on their capabilities and interests. Self-actualization (c.f., Maslow 1943; Maslow 1970) is a powerful motivator therefore playing the role of a potential future career should theoretically produce a highly motivating experience. Students from every iteration reported that having the opportunity to play a professional geologist or emergency manager for the afternoon was a positive aspect of the activity.

Students working in group educational settings are not uncommon in higher education, though activities with large teams (more than 8 or 10 students) are rarer, as they are structurally and logistically more difficult to facilitate. A strong motivational aspect is the general attraction to working with others (i.e., relatedness; Ryan and Deci 2000), in an interdependent and supportive learning environment. Recognition among colleagues is a documented motivator (Maslow 1943). In general, this induces an element of pressure to perform at one's best (Slavin 1984; Hamilton, Nickerson and Owan 2003; Cruz and Pil 2011). Peers, team leaders and instructors all observe the collective effort that they make to complete the tasks. Holding each student accountable provides the incentive for teaching and learning with one another. We did observe and accept that some of the roles were less 'important' and that this may have created differential levels of motivation, accountability and feelings of group cohesiveness. More time working together as a team prior to the simulation allowed students to assess capabilities better and in general student feedback was very positive about job sharing, helping each other out and the interdependency on one another (e.g., Section 5.4.3; paragraph six).

There were many motivation theory aspects that were considered during the design and development of this simulation. Using real (context-apparent) challenges, which replicate professional roles in a crisis provided opportunities for students to experiment and experience the responsibilities of mitigating a disaster.

5.5.3 Communication and Team Behaviour

Communication and teamwork were critical to several of the learning goals of the Volcanic Hazards Simulation (Table 5.2). There is a call for graduates to excel at these skills (e.g., Ireton et al. 1997). The crisis scenario provides a platform upon which students can discover the quality, efficiency, urgency, and importance of these skills: “Seeing the ‘chain of command’ appearing and taking charge of what needed doing and seeing [the students] effectively disseminate the information. I think as soon as they realized that teamwork and communication was important, it worked a lot better” (Pilot, Instructor 2) and “I thought all the information given to us, thrown at us really, was realistic. I think in [a crisis] situation there is too much information” (Iteration 1, Public Information Officer 2).

Effective communication pathways or information “infrastructure” (Celik and Corbacioglu 2010) is vital for a team to work efficiently. This study showed that engineering more effective communication pathways (through specific roles, increased awareness of team structure and preparation activities) produced more straightforward information transfer and thus successful decision making and mitigation of the impending disaster. By providing more nodes (or in this case more students, and more roles) we observed that the student’s efficiency increased and therefore improved the flow of information, and reduced “bottlenecks”. This prevented major oral miscommunications, although a lack of efficiency during times of stress persisted: “[The Emergency Management] team didn’t get stuff from the scientists fast enough” (Iteration 3, Infrastructure)), when information was not passed along quickly enough.

Communication efficiency improved throughout the simulation. In each iteration, we observed students gradually acquiring familiarity with the correct protocols and a level of comfort with this structure. The information ‘bottlenecks’ students reported frustration with the inefficient of the information system (Iteration 1, "The communication between us and the other geologists was hard because we had to communicate through [the team leader]. And [the team leader] was too busy with everything sometimes to relay it" (Iteration 1, Field Geologist)). Building awareness of the importance and inherent difficulties of information transmission was one of our major learning goals (Table 5.2, goal 5) and was reported by the students in all simulation iterations.

By scaffolding the students communication skills prior to (delivery of best practices) and during the simulation (through instructor interventions) more quality communications were observed in later iterations. The best practices presented to students focused specifically on being terse and contextual, but "packaging" only the relevant information into a communiqué was a large challenge reported by many students. Only through meaningful practice were the students observed to achieve this learning outcome ("I relayed only the 'need-to-know' information" (Iteration 3, Volcano geophysicist)). Providing strong team and role structure improved communication pathways and communication efficiency, allowing members to think about the *quality* of the communications.

Effective collaboration and crisis mitigation, requires team members to actively communicate and interact with each other with the intention of establishing a common focus and achieving a common goal (Beers et al. 2006; Akkerman et al. 2007). Effective decision-making requires all team members to have access to all relevant information (Beers et al. 2006; Sellnow et al. 2009). To create and disseminate successful communications, valuable knowledge and information held by each team member must actively be shared (i.e., retrieving and explicating information), discussed (i.e., processing the information) and remembered (i.e., personalizing and storing the information) (Kirschner, Paas and Kirschner 2009). The leader of the team was responsible for coordinating this effort.

There were examples of strong (Iteration 3, Group Controller; Iteration 2, Volcanic Section Manager) and poor (Iteration 1 and 4 Volcanic Section Manager) team leadership throughout the iterations. Team leaders (Iteration 1 and 4 Section 5.4.3) who displayed poor leadership skills negatively affected the team's decision-making ability. This is likely due to the inability to guide the decision making process and help the team members reach a consensus (e.g., Section 5.4.3, negative group behaviours, paragraph 15).

We identified other roles within the simulation that were "pivotal" to the success of the team. These roles were carefully assigned in Iteration 3 and 4 and resulted in observed and self-reported positive team dynamics (e.g., Iteration 4, "We all provided our individual ideas of events, contributing to all aspects" (Iteration 4, Infrastructure Manager)). In the future, we plan to improve team structure and cohesiveness through team-bonding preparatory activities. If the team structure and norms are established prior to this intense experience, perhaps we would observe more positive and sophisticated behaviours.

5.5.4 Limitations of Study

Design-based research presents difficulties different to those of experimental research. The interconnectivity of participants and outcomes makes segregation of causal relationships difficult. Further study is required to isolate and address specific causal relationships around student success at achieving specific learning goals.

In addition, it is important to acknowledge that the researcher (Dohaney) was heavily embedded in the learning environment (as a teacher, colleague and peer to the participants and the instructors). Validity of the research is difficult to achieve if the researcher cannot identify bias and manipulative control over what results are deemed relevant to the study. As the researcher is intimately involved with conceptualization, design, development, implementation and researching of the pedagogical approach, then ensuring trustworthy assumptions is a challenge (Barab and Squire 2004). Researcher-defined systematic alteration of the designed context could potentially contribute to self-fulfilling findings. There were and are safeguards to eliminate bias and gain an objective perspective on the results and interpretations:

- The researcher did not participate directly in the simulations (with the exception of the Pilot). Dohaney was a passive observer and did not interrupt, change, alter or intervene during the activity.
- In Iteration 3 and 4, Dohaney was the primary instructor of the communication best practices, as there was no other appropriate instructor with the necessary expertise to implement this component. The delivery and transfer of information and skills from these preparation activities was not the research question, but how that information was used during the simulation.
- To avoid bias in data selection, representative quotes were taken that illustrated majority and minority perceptions. They were selected based on data "richness" and characterization of the themes identified. For example, when asked about teamwork, students who described any range of experiences would be included in a 'first pass' of the data. When saturation had been reached, assessments of "majority", "minority" and depth of responses were culled and grouped based on the pedagogical themes.

There were many difficulties with the synthesis of this study, and due mostly to the inherent complexity of studying authentic and interacting phenomena with different student cohorts in different pedagogic environments. However, this inductive approach was beneficial for illuminating the fundamental design variables that were crucial to the success of the simulation and achieving its learning outcomes.

5.6 CONCLUSIONS

Pedagogy and design influenced by real-world expertise and practices can lead to educationally-useful learning strategies. This study concludes that:

1. Careful use of role-play with well-defined team and individual roles, allows students to work together to mitigate a volcanic crisis and achieve learning goals that are transferable to future careers.
2. The findings in this study can act as a guide for other researchers and instructors to build, test, refine and play with complex simulations, allowing researchers to develop flexible, adaptive theory applicable to new contexts.

The learning environment is as relevant to its outcomes as the content of the activity. This study was built into the local context, culturally, nationally and within the department from which it emerged. These yield significant logistical factors not discussed in this chapter, which are important for instructors intending to use a scripted role-play specific to an environment. Major considerations include: A. location, time and space available to the instructor; B. content knowledge of students regarding background information and group and communication skills; and C. time commitment from students and instructors, including all preparation activities (Van Ments 1999).

We show that that this learning activity is of great value for teaching and learning transferable skills and promoting students' self-efficacy and motivation. In the role-play, students challenged themselves and moved outside of their "academic comfort zone" when required to rapidly synthesize new information and prior knowledge at an appropriately difficult level. Challenging students in this manner is closely related to the type of experience they will have employed as part of a team.

Lastly, the interconnected tasks in the role-play required the coordination and integration of constituent skills from the very beginning and pushed learners to quickly develop a holistic vision of the whole task (a more expert schemata). This approach to learning skills through authentic challenges builds confidence and resiliency in students who are likely to become a part of the geologic and emergency management community.

CHAPTER 6: CONCLUSIONS

This chapter summarizes the major findings and contributions it concludes with a discussion of future research directions. Recommendations and implications are also included for geoscience educators and the research community.

The overall purpose of this thesis was to explore skills-based learning and Constructivist teaching strategies in a variety of learning environments within the geosciences by pursuing answers to the major research questions in Table 6.1. To answer those questions, four curricular and experimental research projects were designed, implemented and resulted in the Major Findings in Table 6.1. A naturalistic approach (Lincoln and Guba 1985) was used for the four research projects to utilise qualitative and quantitative data in the natural settings of these four different geoscience learning environments.

Table 6.1: Summary: Research Questions and Major Findings

Chapter	***Research Questions***	***Major Findings:***
Chapter 2: Lab curricula and group work	Does providing applied and customized projects improve engagement in the lab learning experience? What elements of group work promote learning in this setting?	The group work and project-based approach to teaching mineralogy labs yielded positive student feedback. Based on pre-post test results, group work contributed to better student performances individually and as a group. The optimal group size for this curriculum was discovered to be three or four students. This lab curricula format may be suitable for other natural sciences with similar content and skills-based goals and norms.
Chapter 3: Games-based learning of field skills	Can we utilize videogames to achieve equivalent learning gains to a field activity? What are the positive and negative aspects of learning field skills with videogames?	The skills test results indicated that both learning activities are capable of generating positive learning experiences and equivalent learning gains. The game showed to be successful at teaching people from all backgrounds (age, gender, academic background, field experience and videogame experience) about geothermal hot springs. The videogame showed higher positive changes in awareness and sophistication in some categories of observations over the field activity.
Chapter 4: Best practices and classification of note-taking in the field	What factors affect a learner's abilities to take notes in a field environment?	Two best practice metrics for assessing note-taking ability in the geosciences are suggested: uniqueness and completeness. Students with more field experience exhibited higher levels of Unique note-taking. The students perceived previous fieldwork to be of value in their current note-taking abilities. The lecturer's pedagogy was shown to affect performance by including extraneous information during the field lesson and overwhelming the novice note-takers. Female students had statistically significantly higher Completeness values than males; they achieved this by writing statistically *more* during the lesson. Suggestions for improvement were included for instructors and students.
Chapter 5: Complex, authentic volcanic crisis simulation	What elements of design affect the individual and collective (team) behaviors and perceptions of learning in a complex simulation?	There were several important design variables which were shown to affect student's performance and perceptions of this complex learning activity: the pace, the level of preparation, authenticity of roles and teams and detailed preparation including communication best practices. Iterative design changes resulted in a more successful outcome, yielding more sophisticated student behavior.

6.1 MAJOR FINDINGS AND CONTRIBUTIONS

The major contributions in Table 6.1 from the four research projects range from iterative curriculum design and testing to interpretations of student performance and behaviour. The learning activities designed for this study supported students to achieve a wide range of learning goals from Bloom's taxonomy (Bloom et al. 1956; Isaacs 1996; Lord and Baviskar 2007), all with the common goal of utilising different learning environments to produce geoscience graduates with expert-like attributes, behaviours and skills.

The Chapters in the thesis progressed from traditional teaching and learning environments in geoscience courses (Chapter 2: Mineralogy labs and Chapter 3: Field note-taking skills) to novel, innovative and generally more radical approaches and environments (Chapter 4: Geothermal field skills videogame and Chapter 5: Volcanic hazards scenario-based role-play simulation).

Chapter 2 investigated the development and testing of group learning in a mineralogy laboratory setting. This research into group work revealed that smaller groups of three and four students are optimal for the setting and students' performance. The three major contributions from this study are: 1. Applying student feedback and educational best practices to redesign laboratory assignments produces improved student learning and perceptions; 2. Students can achieve higher levels of thinking (than is traditionally expected in this environment) through appropriate group work and project-based pedagogy; and 3. Group size significantly affects students' behaviour and learning.

Chapter 3 explored the theories, classification and practices of geologic note-taking in the field environment. Data collected from 42 notebooks from a geothermal field lesson and analysed using two semi-quantitative metrics (uniqueness and completeness) to characterization of student’s note-taking ability. The study found that previous field experience, gender and teaching style significantly affect student outcomes.

Both Chapter 2 and 3 are studies that contribute to our understanding of the teaching and learning of core curricula in traditional teaching and learning environments for undergraduate geoscience. Future research in these areas is discussed in Section 6.3.

Chapter 4 introduced a world-first, three-dimensional videogame, GeoThermal World, designed to teach students geology field skills. These practical skill sets include low-level learning goals (recording, observing) that are not often ***explicitly*** taught. The research on GeoThermal World showed statistically equivalent learning gains (on an observation skills recall test) to an actual field lesson. The game can be used as preparatory or supplementary activities to assist students achieve learning expectations. By progressively building their observation and note-taking skills, students without field access can explore an introductory (virtual) field lesson on their own time and their own terms.

Chapter 5 describes a design-based study of the development of a novel, complex role-play simulation. A naturalistic approach to the project revealed specific aspects of the complex design, which had a major affect on the simulation’s success. Students found that this authentic learning activity challenging as it required them to use geologic and transferable skills (higher order thinking in Bloom’s Taxonomy) to mitigate a simulated imminent volcanic disaster. This simulation is used as a capstone learning activity in the undergraduate curriculum at the University of Canterbury and other New Zealand institutions with the intention of preparing students for work in the emergency management and professional sectors.

Both Chapter 4 and 5 are design-based research projects illustrating the benefits of using innovative teaching and learning strategies. Chapter 4 demonstrates that a virtual learning environment can produce learning gains statistically equivalent to an introductory field lesson in a geothermal setting, while Chapter 5 illustrates that the meticulous design of a complex role-play simulation can provide fruitful, meaningful experiences for undergraduate students to develop transferable skills needed for the workplace. The curricula used in these studies required several years of development and engineering. We have showed that the time and resource investment in the careful development and design of these curricula can save costs and resources while providing more access for students to these kinds of experiences.

6.2 IMPLICATIONS AND RECOMMENDATIONS

Overall this thesis examines diverse multi-environment, Constructivist learning in the geosciences. The study required a range of methods paired to the research questions. The findings in this study suggest that effective curriculum design benefits from consideration and application of appropriate educational theories and practices.

The requirements of the 21st century instructor differ from those of the previous decades. These four different research projects have contributed to the field of geoscience education and research because they examine the effects of different teaching modes on student learning outcomes.

This thesis has systematically examined effective best practices in skills-based geoscience activities. The goals-based approach assisted in the development of the skills-based curricula however, some of the skills that we aimed to teach were *not* (at this time in geoscience education research), in fact, measureable. Transferable skills and geoscience field skills in particular (the teaching of which were the major goals of Chapters 3, 4 and 5) are not well-studied and their teaching is institutionally and culturally varied. Future research will allow me to look into areas of skill development in the geosciences, across broader cultural-national contexts in order to improve our understanding of their teaching and learning.

Chapter 2 can inform the teaching of inquiry-based, laboratory curricula in the natural sciences. Additionally, group work can be used in this way in lectures, lecture-tutorials and laboratory settings in order to encourage peer learning in larger classes. The results and suggestions from Chapter 3 indicate that small changes to pedagogy may influence teaching strategies used in the field. Note-taking best practice should be considered and explicitly addressed by both students and lecturers. Scaffolding and breaking down complex tasks into simple ones can reduce the difficulty of note-taking for novices.

GeoThermal World (studied in Chapter 4) opens up a whole new world (i.e., the “virtual” world) to be used and explored by geoscientists and geoscience educators. Videogames have been used and studied in other disciplines to teach basic skills. We have shown that they can be used to teach simple geoscience skills and future work will be focused on complex geoscience problems and skills. Educational technology promises to break the barriers of physical disabilities for students, which can make teaching field geology more equitable. Additionally, students or institutions with financial limitations can benefit from this educational technology.

The long term design projects in Chapters 4 and 5 required a significant time investment. Few geoscience educators can dedicate themselves entirely to curricular development; however, this thesis demonstrates how effective and motivating these activities are for students. I recommend to educators and researchers that long term investment in these sorts of learning activities will add higher-level (i.e., Bloom's goals) challenges to students who will be soon entering the workforce and promote greater learning gains than more static and staid teaching methods.

Finally, Chapter 5 demonstrates that undergraduate students can perform well in authentic, complex, high stress environments, which are similar to real work settings. Developing and implementing these simulations is resource-intensive for the educator, but once the curricula are established they are very effective capstone teaching experiences in the undergraduate-postgraduate curriculum. Chapter 5 shows that scenario-based curricula helped students to develop transferable skills while simultaneously, exemplifying their importance. Although the simulation was designed in the New Zealand context, replicable scenario-based role-plays could be used to teach transferable skills in the geosciences anywhere. Educators need to address the teaching of these skills in a more explicit, structured manner, which is context-apparent and feedback-rich (i.e., scenario-based learning). These scenarios allow students to practice new skills prior to going into the workplace, where it is expected that they will have these graduate attributes.

6.3 FUTURE RESEARCH & FINAL THOUGHTS

As research continues to advance our understanding of teaching and learning, novel and innovative activities will be created and instilled into the undergraduate curricula. Many new questions and new research directions were uncovered while writing this thesis. The following is a succinct list of new lines of inquiry to be explored in the future (Table 6.2).

Table 6.2: Future Research

Topic	***Research Questions***
Group work in optical microscopy courses	Can students learn microscopy more effectively together? What are the benefits to this approach?
Games-based virtual geology	Can we use games to teach other field skills? More advanced skills?
Geoscience students' motivational aspects of educational technology	What are students' perceptions of handheld technology in the field? What are the positive aspects? The negative aspects?
Testing and design of handheld note-taking technology	What are the strengths and weaknesses of note-taking technology and can it make note-taking more effective?
Note-taking best practices	What are additional qualities of note-taking best practice? Efficiency, Verbosity?
Note-taking best practices expertise	How/when do learners acquire these in order to become experts? What do 'expert' notes look like?
Complex scenario-based role-play and simulations	What are the quantitative means to measure effective curricular design? Can we apply/use of scenario-based role play in other natural hazards scenarios (e.g., earthquakes, floods)?
Communication best practices	How do we define communication best practices in the geosciences? How can we measure science communication?

Final Thoughts

Fundamentally, this thesis favours the Constructivist axiom of ‘learning by doing’. This teaching paradigm offers a sound theoretical frameworks for improving the conceptual knowledge, skills and perceptions of students in all disciplines. However, there are many other effective approaches which are suited to the needs of a given discipline. Geoscience is an observation-based science with field trips and hands-on labs. Medical sciences, nursing, engineering and other field-based natural sciences have all acknowledged the vital need for and embraced situated learning experiences that expose the learner to real world challenges requiring practical skills. Institutes and industry partners have long advocated for improved applied and transferable skills in our graduating geology students. Geoscience education researchers should respondwith programmes based on student learning data to provide students with appropriate knowledge, skills and attitudes to become responsible and capable geologists.

This thesis has demonstrated to me that even small, incremental application of cognitive load and motivational theories to current practices can be significant to the students’ learning experience. For example, we made changes to the curricula to be more learner-centred and collaborative (Chapter 2) and used applied and authentic scenarios (Chapter 2 and Chapter 5) to demonstrate the knowledge in context. Additionally, the experimental and design projects used in this thesis can be considered a guideline for first time geoscience educators who want to make small or radical transformations in their teaching practices. A primary suggestion is to begin the project by examining the educational psychology literature to assess how theoretical constructs might influence your teaching.

Concerning educational policies, some institutions have opted for reduction and removal of fieldwork within their curricula. While most geologists will fundamentally disagree with these changes, they must consider how to continue to create learning experiences for students to attain the necessary learning outcomes within constrained resources. In addition to fieldwork, there are many learning strategies that challenge students in meaningful ways, which cannot be accomplished with traditional means. Novel learning activities to engage and train students for the tasks central to their careers need to be encouraged and supported.

Educational technology provides the medium for instructors and researchers to develop robust simulations and media. The future of education will rely heavily on educational technology – but each new tool and its interface should be rigorously tested. However, technology should not replace the valuable experience that students and instructors gain from the discourse and interactions that arise from face-to-face learning. Instructors and institutes should use multi-learning approaches which scaffold learner’s experiences while challenging students to improve their knowledge and skills.

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CHAPTER 8: APPENDIXES

APPENDIX A – PUBLICATIONS INCLUDED IN THESIS

A1. Correspondence from the Journal of Geoscience Education

Permission to include a publication in my Doctorate
5 messages

Jacqueline Dohaney <jdohaney@gmail.com> Wed, Jan 9, 2013 at 3:26 PM
To: Journal of Geoscience Education <jge@jmu.edu>
Cc: Erik Brogt <erik.brogt@canterbury.ac.nz>, Ben Kennedy <ben.kennedy@canterbury.ac.nz>

Dear Kristen St. John,

I am writing to you to ask for permission to include a publication in my dissertation document. I have CC'd the co-authors (my supervisors), who have given permission.

My University requires that we get written permission from the editor of the journal in which the article is published.

Please see the attached document (this is from the University policy). I have highlighted the part that is relevant to getting permission from the journal.

The publication in question is:
http://www.nagt-jge.org/doi/abs/10.5408/10-212.1

If there is additional information needed, please don't hesitate to ask.

Thanks & Cheers,
Jacqueline Dohaney

publicationsinathesis.docx
20K

Journal of Geoscience Education <jge@jmu.edu> Wed, Jan 23, 2013 at 3:51 AM
To: Jacqueline Dohaney <jdohaney@gmail.com>

Hi Jacqueline,

I'm glad you resent the email. I didn't see it earlier. Yes, you have my permission to reprint the article i your dissertation. In the reprinting, please be sure to include the full citation to the original publication.

Kind regards,

Kristen

Dr. Kristen St. John

Editor-in-Chief

https://mail.google.com/mail/?ui=2&ik=ac5a31ad5d&view=pt&search=inbox&th=13c1d20fa2bdeb31 1/2

1/23/13 Gmail - Permission to include a publication in my Doctorate

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395 S. High St.
James Madison University
Harrisonburg, VA 22807
Phone: (540)568-6675
Fax: (540)568-8058

A2. Correspondence from the New Zealand Geothermal Workshop Organiser

Permission to include a publication in my Doctorate

3 messages

Jacqueline Dohaney <jdohaney@gmail.com> Wed, Jan 23, 2013 at 12:01 PM
To: Emily Clearwater <ecle011@aucklanduni.ac.nz>
Cc: Erik Brogt <erik.brogt@canterbury.ac.nz>, Ben Kennedy <ben.kennedy@canterbury.ac.nz>, Hazel Bradshaw <hazel.bradshaw@canterbury.ac.nz>

Dear Emily,

I am writing to you to ask for permission to include the workshop proceedings paper in my dissertation document. I have CC'd the co-authors (my supervisors), who have given permission.

My University requires that we get written permission from the editor of the journal in which the article is published.

Please see the attached document (this is from the University policy). I have highlighted the part that is relevant to getting permission from the journal.

The publication in question is:
http://www.academia.edu/1906988/The_GeoThermal_World_Videogame_An_Authentic_Immersive_Videogame_Used_to_Teach_Observation_Skills_Needed_for_Exploration

If there is additional information needed, please don't hesitate to ask.

Thanks & Cheers,
Jacqueline Dohaney

publicationsinathesis.docx
20K

Emily Clearwater <ecle011@aucklanduni.ac.nz> Fri, Jan 25, 2013 at 10:35 AM
To: Jacqueline Dohaney <jdohaney@gmail.com>

Hi Jacqueline,

No problem, the committee are happy to give permission. Here is an official sounding statement:

I, Emily Clearwater, of the 2012 New Zealand Geothermal Workshop (NZGW) Organising Committee, give permission for Jacqueline Dohaney to include the work "The GeoThermal World Videogame: An Authentic Immersive Videogame Used to Teach Observation Skills Needed for Exploration", published in the 2012 proceedings, into her dissertation document.

Emily Clearwater
The University of Auckland

We are organising an ISBN (or ISSN) number for the proceedings, so that they are identified as an official publication. That might be useful to add into your references, so I can email it through to you once we have it organised.

Cheers,
Emily.

P.S. Congratulations on winning the NZGA prize for your paper :-)
[Quoted text hidden]
--
Emily Clearwater
Research Assistant
Department of Engineering Science
University of Auckland

A3. Co-authorship Form – Chapter 2

Deputy Vice-Chancellor's Office
Postgraduate Office

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Co-Authorship Form

This form is to accompany the submission of any thesis that contains research reported in co-authored work that has been published, accepted for publication, or submitted for publication. A copy of this form should be included for each co-authored work that is included in the thesis. Completed forms should be included at the front (after the thesis abstract) of each copy of the thesis submitted for examination and library deposit.

Please indicate the chapter/section/pages of this thesis that are extracted from co-authored work and provide details of the publication or submission from the extract comes:

Chapter 2: "Successful Curriculum Development and Evaluation of Group Work in an Introductory Mineralogy Laboratory"

Co-authors: Dr. Ben Kennedy, Dr. Erik Brogt

Please detail the nature and extent (%) of contribution by the candidate:

Dohaney was responsible for all data collection, marking, and creation of curricular materials.

Dohaney drafted all figures, preliminary results and wrote the manuscript, and validated the final version which was published. Dohaney (80%)

Dr. Kennedy was integral in the decision-making around curricular direction, and shared in feedback collection in a focus group. He was part of the conception and design process.

Dr. Brogt assisted in the analysis and interpretation of the test data.

Both Dr. Kennedy (10%) and Dr. Brogt (10%) assisted in the editing process and preparation of the manuscript and took part in the final approval of the version which was published.

Certification by Co-authors:

If there is more than one co-author then a single co-author can sign on behalf of all

The undersigned certifys that:

- The above statement correctly reflects the nature and extent of the PhD candidate's contribution to this co-authored work
- In cases where the candidate was the lead author of the co-authored work he or she wrote the text

Name: *Dr. Ben Kennedy* Signature: Date: *April 9, 2013*

Name: *Dr. Erik Brogt* Signature: Date: *April 9, 2013*

A4. Co-authorship Form – Chapter 3

Deputy Vice-Chancellor's Office
Postgraduate Office

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Co-Authorship Form

This form is to accompany the submission of any thesis that contains research reported in co-authored work that has been published, accepted for publication, or submitted for publication. A copy of this form should be included for each co-authored work that is included in the thesis. Completed forms should be included at the front (after the thesis abstract) of each copy of the thesis submitted for examination and library deposit.

Please indicate the chapter/section/pages of this thesis that are extracted from co-authored work and provide details of the publication or submission from the extract comes:

Chapter 3: "Field Note-taking and Perceptions: Towards Classification and Best Practices".

Co-authors include: Dr. Erik Brogt and Dr. Ben Kennedy

Please detail the nature and extent (%) of contribution by the candidate:

Dohaney was responsible for: the conceptual framework and the design of the experiment, the instruments used, the methodology carried out. Dohaney performed the analysis, the coding of the notebooks and interviews. Dohaney drafted the manuscript and all of the figures and was responsible for the final approval of the manuscript prior to submission. Dohaney (80%)

Dr. Brogt (12%) and Dr. Kennedy (8%) assisted with editing, suggestions during analysis and writing of the manuscript. Dr. Brogt was part of the original concept and design process and the interpretation of results. Dr. Kennedy took part in the analysis and interpretation of results. Both were part of the final approval of the manuscript prior to submission.

Certification by Co-authors:

If there is more than one co-author then a single co-author can sign on behalf of all
The undersigned certifys that:

- The above statement correctly reflects the nature and extent of the PhD candidate's contribution to this co-authored work
- In cases where the candidate was the lead author of the co-authored work he or she wrote the text

Name: *Dr. Erik Brogt* Signature: Date: *April 9, 2013*

Name: *Dr. Ben Kennedy* Signature: Date: *April 9, 2013*

A5. Co-authorship Form – Chapter 4

Deputy Vice-Chancellor's Office
Postgraduate Office

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Co-Authorship Form

This form is to accompany the submission of any thesis that contains research reported in co-authored work that has been published, accepted for publication, or submitted for publication. A copy of this form should be included for each co-authored work that is included in the thesis. Completed forms should be included at the front (after the thesis abstract) of each copy of the thesis submitted for examination and library deposit.

Please indicate the chapter/section/pages of this thesis that are extracted from co-authored work and provide details of the publication or submission from the extract comes:

Chapter 4: "The GeoThermal World Videogame: An Authentic, Immersive Videogame Used to Teach Observation Skills Needed for Exploration"

Co-authors: Dr. Ben Kennedy, Dr. Erik Brogt, Hazel Bradshaw

Please detail the nature and extent (%) of contribution by the candidate:

Dohaney piloted the concepts and designed the experiment and the instruments used in this study. Dohaney wrote the manuscript, and drafted the figures and results. Dohaney was the geosciences designer (i.e. wrote the narrative, researched the geoscience content and educational impact of the videogame). Dohaney (80%)

Dr. Kennedy (7%) and Dr. Brogt (7%) were part of the analysis and interpretation of data; and took part in the revisions, gave recommendations on the manuscript and were part of the final approval process.

Design of the videogame was shared with Hazel Bradshaw (6%; HITLab, UC). Hazel is the producer and visual designer of the videogame. She essentially built the world, tools and interface of the videogame. Hazel provided some feedback for revision, and took part in the final approval process.

Certification by Co-authors:

If there is more than one co-author then a single co-author can sign on behalf of all

The undersigned certifys that:

- The above statement correctly reflects the nature and extent of the PhD candidate's contribution to this co-authored work
- In cases where the candidate was the lead author of the co-authored work he or she wrote the text

Name: *Dr. Ben Kennedy* Signature: Date: *April 9, 2013*

Name: *Dr. Erik Brogt* Signature: Date: *April 9, 2013*

A6. New Zealand Geothermal Association Paper Award – Chapter 4

NEW ZEALAND GEOTHERMAL ASSOCIATION

New Zealand Geothermal Association Award

For the best paper presented at the 34th **New Zealand Geothermal Conference, 2012**

In the category **"Current innovations in the New Zealand geothermal industry"**

Awarded to:	*Jacqueline Dohaney, Ben Kennedy Erik Brogt and Hazel Bradshaw*
For the paper titled:	***"The geothermal world videogame: an authentic, immersive videogame used to teach observations skills needed for exploration"***

SPENCE McCLINTOCK
NZGA PRESIDENT

APPENDIX B – HUMAN ETHICS APPROVAL

The experiments carried out in this dissertation covered a breadth of geosciences education topics and settings.

An initial application was submitted and approved by the Educational Research Human Ethics Committee (Appendix B1) which covered investigations of students in field and classroom teaching of volcanology and geothermal topics at the University of Canterbury. Another study was proposed, approved and carried out to observe and interview students before during and after the videogame and a replicable field activity. This application was submitted and approved by the Human Ethics Committee at the University of Canterbury (Appendix B2). The results of this study contributed to the authenticity of the Volcanic Hazards Simulation (Chapter 5).

Prior to all studies, participants were provided with study information (Information forms) asked for consent for participation (Consent Forms). Those are included in Appendix B3.

B1. Educational Research and Human Ethics Committee Approval, File ERHEC 2009/86/CoEdn

Ref: ERHEC 2009/86/CoEdn

11 January 2010

Jacqueline Dohaney
Department of Geological Sciences
UNIVERSITY OF CANTERBURY

Dear Jacqueline

Thank you for providing the revised documents in support of your application to the Educational Research Human Ethics Committee. I am very pleased to inform you that your research proposal "Integrating volcanologial and geothermal field courses with 21st centurey learning techniques" has been granted ethical approval.

Please note that should circumstances relevant to this current application change you are required to reapply for ethical approval.

If you have any questions regarding this approval please let me know.

We wish you well for your research.

Yours sincerely

Dr Missy Morton
Chair
Educational Research HEC

"Please note that Ethical Approval relates only to the ethical elements of the relationship between the researcher, research participants and other stakeholders. The granting of approval or clearance by the Educational Research Human Ethics Committee should not be interpreted as comment on the methodology, legality, value or any other matters relating to this research."

B2. Human Ethics Committee, Approval, File HEC 2012/21

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

HUMAN ETHICS COMMITTEE

Secretary, Lynda Griffioen
Email: human-ethics@canterbury.ac.nz

Ref: HEC 2012/21

23 May 2012

Hazel Bradshaw & Jacqueline Dohaney
HITLab, Geological Sciences
UNIVERSITY OF CANTERBURY

Dear Hazel and Jacqueline

The Human Ethics Committee advises that your research proposal "Assessing flow, motivation and learning gains of geothermal concepts from a field-based approach compared to a virtual video game (Geothermal World)" has been considered and approved.

Please note that this approval is subject to the incorporation of the amendments you have provided in your emails of 22 March and 17 May 2012.

Best wishes for your project.

Yours sincerely

Michael Grimshaw
Chair
University of Canterbury Human Ethics Committee

B3. Information & Consent Forms, All studies

B3.1 Information & Consent – Chapter 3 and 4 – Geothermal Observations & Note-taking Study

Geological Sciences
Primary Investigator: Dr. Ben Kennedy
Researcher: Jacqueline Dohaney, M. Sc.
Tel: +64 22 656 6236
Email: jdohaney@gmail.com

Human Interface Technology Laboratory, N.Z.
Primary Investigator: Dr. Mark Billinghurst
Researcher: Hazel Bradshaw
Tel: +64 3 364 2987 ext. 3070
Email: hazel.bradshaw@canterbury.ac.nz

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Information

To the participant in this study -

Assessing flow, motivation, and learning gains of geothermal concepts from a field-based approach compared to a virtual environment (Geothermal World Videogame).

We are PhD students in the Geological Sciences and Human Interface Technology Laboratory at the University of Canterbury. This letter summarizes the information, methods and risks of participating in a study we are undertaking which will be used to evaluate and improve student learning **geothermal** topics. All responses from this study are not graded and will not impact your success in your studies at Canterbury. Please read the statements below. You may ask questions to the researcher at any time for clarification.

Purpose of the project:
The purpose of this project is to assess student successes and behaviour while participating in a videogame called ***Geothermal World***. The objective of the research is to improve geothermal field, lecture, and lab courses for future years and to make learning the subject matter easier, and more fun.

If you participate, you will be asked to:

1. Complete a questionnaire regarding your attitudes about learning new tasks, and how you felt about the videogame.
2. Complete a test to assess your learning before and after playing the videogame.
3. Play a videogame in a classroom with other classmates. You will be observed by the researcher(s) during the videogame, and they will take notes and a video of your behaviours.
4. Complete a one-on-one interview with the researcher(s) to discuss your participation in the learning activities.

This project has received ethical approval from the University of Canterbury Human Ethics Committee

Complaints may be addressed to:
Chair,
Human Ethics Committee
University of Canterbury, Private Bag 4800, CHRISTCHURCH
(human-ethics@canterbury.ac.nz)

Time required for participation:
Videogame: May take 30 mins or more to play
Interviews: May take 10-15 minutes to complete
Questionnaires: May take 5-15 minutes to complete
Tests: May take 5-15 minutes to complete

Risks: There are no notable physical or emotional risks to participating in this study. If you feel uncomfortable with any questions, you may choose not to answer them.

Benefits: The major benefits of this study include: a. The opportunity for the student to think about their learning processes; b. Play a fun videogame that explores educational concepts. C. The opportunity for the student to voice their opinions about their learning in order to make it better for future students.

Voluntary Participation: ***Please note that participation in this study is voluntary***. If you do participate, you have the right to decline to answer any questions and to withdraw from the study at any time prior to publication. The findings of this study may be published and/or reported internationally. Particular care will be made to ensure confidentiality of all data gathered for this study and the anonymity of participants and their schools in all publications of the findings. Each participant will be unnamed, and video or audio files will be altered, or manipulated to maintain confidentiality. All data is to be securely stored in password protected facilities and/or locked storage at the University of Canterbury for five years following the study, and will then be destroyed.

Previous Study – IMPORTANT: Some of the participants in this study were a part of a previous study which was held in February, 2012. The field study was carried out at Orakei Korako, on the GEOL488 fieldtrip. Students gave consent to participate in the study, but at that time – Bradshaw was not explicitly indicated as a primary researcher. If you consent to Dohaney, and Bradshaw sharing this information please indicate on the applicable section of the Consent form (accompanied by this form). If this does not apply to you, please disregard.

If you agree to participate in this study, **please sign the consent letter provided**. If you have any questions about this research, please do not hesitate to contact us. If at any stage you have a complaint about this research, these may be addressed to the Chair of the Human Ethics Committee (see footer for details).

Thank you in advance for your contribution.

Yours sincerely,

Jacqueline Dohaney, M.Sc.
&
Hazel Bradshaw,

This project has received ethical approval from the University of Canterbury Human Ethics Committee

Complaints may be addressed to:
Chair,
Human Ethics Committee
University of Canterbury, Private Bag 4800, CHRISTCHURCH
(human-ethics@canterbury.ac.nz)

Geological Sciences
Primary Investigator: Dr. Ben Kennedy
Researcher: **Jacqueline Dohaney**, M.Sc.
Tel: +64 22 656 6236
Email: jdohaney@gmail.com

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Human Interface Technology Laboratory, N.Z.
Primary Investigator: Dr. Mark Billinghurst
Researcher: **Hazel Bradshaw**
Tel: +64 3 364 2987 ext. 3070
Email: hazel.bradshaw@canterbury.ac.nz

Assessing flow, motivation, and learning gains of geothermal concepts from a field-based approach compared to a virtual environment (Geothermal World Videogame).

Declaration of Consent to Participate:

I have read and understood the description of the above-named project. On this basis I agree to participate as a subject in the project, and I consent to publication of the results on the project with the understanding that anonymity will be preserved.

I understand also that I may at any time withdraw from the project, including withdrawal of any information that I have provided.

I note that the project has been reviewed ***and approved*** by the University of Canterbury Human Ethics Committee.

Additionally, please read and check the box below **if this applies to you**:

I gave consent to a previous field study (at Orakei Korako) in February, 2012 on the GEOL488 fieldtrip and,

☐ **I now acknowledge, and give consent** for that previously collected data to be shared between both of the above researchers (Dohaney, and Bradshaw) as a part of their PhD research. (*Bradshaw was not indicated on the previous consent form.)*

Date:

Name: (Print)

Signature:

Email address *(Optional; allows us to email you the results of the study)*:

*Please **return this completed consent form** to the researcher. Thank you for participating in this study!!*

B3.2 Information & Consent – Chapter 5 Volcanic Hazards Simulation

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Primary Investigator: Dr. Ben Kennedy
Tel: +64 3 364 2987 ext 7775
Email: ben.kennedy@canterbury.ac.nz

Researcher: Jacqueline Dohaney, PhD Student
Tel: +64 22 656 6236
Email: jdohaney@gmail.com

To the participant in this study:

Evaluation of Collaborative Role-play Simulations for Volcanology and Geothermal Topics in Field- and Lecture-based Courses

I am a PhD student in the Geological Sciences department of the University of Canterbury. This letter summarizes the information, methods and risks of participating in a study I am undertaking which will be used to evaluate and improve student learning of **volcanology** and **geothermal** topics. All responses from this study are not graded and will not impact your success in your studies at Canterbury. Please read the statements below. You may ask questions to the researcher at any time for clarification.

Purpose of the project:
The purpose of this project is to assess student success, behaviour, and attitudes during several volcanology and geothermal activities. The objective of the research is to improve Geology field and lecture courses for future years and to make learning the subject matter easier, and more fun.

If you participate, you will be asked to:
1. Complete a one-on-one interview with the researcher to discuss your participation in the learning activities.
2. Complete a questionnaire regarding your attitudes about the module (what you liked, what didn't like, what you think we can change to make the course better)
3. You will be observed by the researcher during the learning activities, and she will take notes and a video of your behaviours.

Time required for participation:
Interviews: May take 10-30 minutes to complete
Questionnaires: May take 5-20 minutes to complete

Risks:
There are no notable physical or emotional risks to participating in this study. If you feel uncomfortable with any questions, you may choose not to answer them.

1. This project has received ethical approval from the University of Canterbury Educational Research Human Ethics Committee

2. Complaints may be addressed to:
   Chair,
   Educational Research Human Ethics Committee
   University of Canterbury, Private Bag 4800, CHRISTCHURCH
   (human-ethics@canterbury.ac.nz)

Benefits:
The major benefits of this study include:
1. The opportunity for the student to think about their learning process
2. The opportunity for the student to voice their opinions about the learning activities in order to make it better for future students

Voluntary Participation:
Please note that participation in this study is voluntary. If you do participate, you have the right to decline to answer any questions and to withdraw from the study at any time prior to publication. The findings of this study may be published and/or reported internationally. Particular care will be made to ensure confidentiality of all data gathered for this study and the anonymity of participants and their schools in all publications of the findings. Each participant will be unnamed, and video or audio files will be altered, or manipulated to maintain confidentiality. All data is to be securely stored in password protected facilities and/or locked storage at the University of Canterbury for five years following the study, and will then be destroyed. All participants will receive a report on the findings of this study.

If you agree to participate in this study, **please sign the consent letter provided**. If you have any questions about this research, please do not hesitate to contact me. If at any stage you have a complaint about this research, these may be addressed to the Chair of the Educational Research Human Ethics Committee (see footer for details).

Thank you in advance for your contribution.

Yours sincerely,

Jacqueline Dohaney, M.Sc.

Jacqueline Dohaney, PhD Student
Tel: +64 22 656 6236
Email: jdohaney@gmail.com

Evaluation of Collaborative Role-play Simulations for Volcanology and Geothermal Topics in Field- and Lecture-based Courses

Declaration of Consent to Participate

I have read and understood the information provided about this research project.

I understand that my participation is voluntary and that I may withdraw at any time prior to publication of the findings.

I understand that any information or opinions I provide will be kept confidential to the researcher and that any published or reported results will not identify me or my institution.

I understand that all data from this research will be stored securely at the University of Canterbury for five years following the study.

I understand that the raw data collected from this research will be destroyed after five years following the study

I understand that the findings of this study will be available and that I will receive a report and have provided my email details below for this purpose.

By signing below, I agree to participate in this research project.

Name:

Date:

Signature:

Email address for report on study:

(Note: email confirmation will be sent on receipt of your survey)

*Please **return this completed consent form with the questionnaires** to the researcher.*

Thank you for your contribution to this study.

1. This project has received ethical approval from the University of Canterbury Educational Research Human Ethics Committee

2. Complaints may be addressed to:
   Chair,
   Educational Research Human Ethics Committee
   University of Canterbury, Private Bag 4800, CHRISTCHURCH
   (human-ethics@canterbury.ac.nz)

APPENDIX C – CHAPTER 2

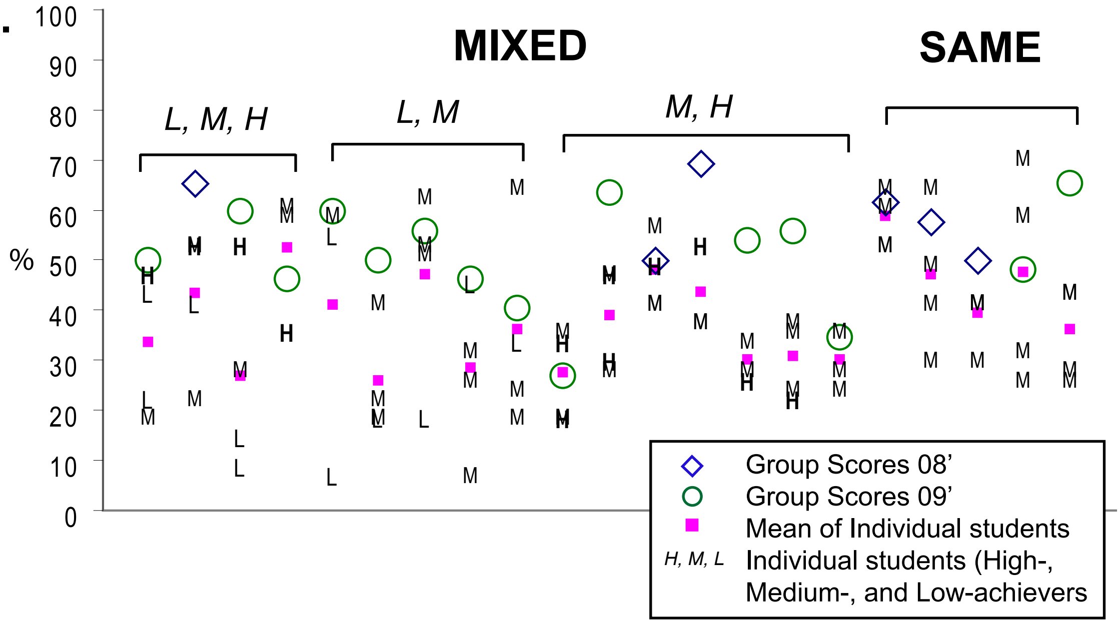
In order to determine whether group work was more or less successful for differing talents (or intellectual abilities), we assigned students to categories based on their final course grades. The table in Figure C1.A shows the criteria by which students were assigned to these categories. Figure C1.B illustrates the difference between group scores (%) and the mean score of all the group members (High– (H), Medium– (M), and Low- (L) achievers) in a group size of four for pre-test scores in 2008 and 2009. The table in Figure C1.C illustrates that in our study, there is no major difference between homogenous and heterogeneous groups.

Figure C1: Effects of mixed or same-talent abilities on group and individual scores. A. Grading criteria for which students were assigned into specific talent categories in 2008 and 2009. B. Pre-test scores of groups with four students in 2008 and 2009, sorted into their respective talent make-up. C. A table showing that statistically, there is no major difference between homogenous and heterogenous ability groups.

A.

Year	n	Mean Course Grade (μ)	σ	Assigned Categories	n per Category
2008	112	69.65	8.37	Low (scores < -σ) = < 61.28% Medium (-σ to σ) = 61.28% – 78.03% High (scores > σ) = >78.03%	L = 18 M = 75 H = 19
2009	103	70.47	9.25	Low (scores < -σ) = < 61.22% Medium (-σ to σ) = 61.22% – 79.73% High (scores > σ) = >79.73%	L = 16 M = 72 H = 15

B.



C.

Same Talent Groups	2		3		4		5		6	
	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009
n=	1	1	1	5	3	2	0	0	0	0
Mean Group Score (%)	62	46	62	47	56	57	-	-	-	-
Mean of Mean Student Scores	40	33	56	38	48	42	-	-	-	-
Mean of Top Students per group	50	42	77	52	58	58	-	-	-	-
Mean Range of Group	19	19	42	28	22	31	-	-	-	-
Mixed Talent Groups	**2**		**3**		**4**		**5**		**6**	
	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009
n=	0	1	5	7	3	14	12	0	2	1
Mean Group Score	-	54	52	34	62	49	48	-	48	42
Mean of Mean Student Scores	-	36	42	28	45	35	48	-	48	36
Mean of Top Students per group	-	52	52	36	55	49	61	-	62	67
Mean Range of Group	-	33	22	17	21	29	26	-	40	58

APPENDIX D – CHAPTER 5

The following appendixes are included from Chapter 5. These include instruments used (D1, 2, and 5) and curricular materials developed to support learning (D3, 4, 6, 7).

D1. Semi-Structured Interview Questions

The following questions were asked in a semi-structured one-on-one post-interviews carried out by the researcher (Dohaney) and an assistant (Hearne, Rebecca) following Iteration 1:

Academic Background:
Can you tell me a little bit about your academic background (degree program, courses)?
GEOLXXX, ENGEXXX or Both? What motivated you to take this/these course(s)?
What interests you about this/these course(s)?

Geology Content:
List the 4 major volcanic hazards associated with stratovolcanoes
Describe the 6 major data types used for monitoring stratovolcanoes
Discuss the differences between two different eruptions (the volume and distribution):
An eruption with a plume height of 2 km, and duration of 20 minutes, vs.
An eruption with a plume height of 15 km, and duration of 2 hours
Describe the short term impacts that 2 cm of ashfall would have on an urban area
Describe the long term impacts that 2 cm of ashfall would have on an urban area
Can you describe the GNS Alert Levels, and your thoughts on their use during this exercise?

Feedback:
What "team" were you a part of?
What individual role did you play? Tell me a little bit about your role before and during the exercise.
Tell me about the communication between yourself, your team and the other teams.
Tell me about the hazard map created by your class, and its function throughout the activity
Tell me about the emergency hazard plan that was designed, used, and re-assessed during this activity.
Do you think this simulation reflects volcanic monitoring and volcanic crisis management in reality? Why or why not?
Based on the your background education, and this exercise, what do you think about the prediction of volcanic activity?
Talk a little about your interaction with the 'experts'?
What parts of the activity would you keep? Why?
What parts of the activity would you change? Why?

D2. Post-Questionnaires

Two questionnaires were used in this study. Appendix D2.1 was used for Iteration 2, and Appendix D2.2 for Iterations 3 and 4.

D2.1. Participant Questionnaire (Iteration 2)

(The following questions were posed to students in a questionnaire administered in the evening of the day that students participated in the simulation. Part I and II consisted of demographics information, and geologic concepts relevant to the background needed for the simulation gameplay. These sections have been omitted. Formatting of this questionnaire allowed ample writing space for students to record their thoughts with little difficulty.)

Name: **Role:** **Day/Time:**

Part I. Demographics (not relevant to this study)

Part II. Geology Questions (not relevant to this study)

Part III. Questions about your Experience:
Instructions: The following questions are open-ended and are for us to understand how you experienced the simulation and the role that you played. Use your own words and please use examples to help you, if necessary. If you need more room, flip over the page and continue.

1. Did you feel sufficiently prepared for the simulation? Did the literature, lectures, exercises help before the simulation? Which was most helpful? Why?
2. Describe your role during the simulation: A. your responsibilities and A. what you spent most of your time doing.
3. Did you personally identify with the role that you played? Explain.
4. Could you see yourself working in this job in real life? What makes this job attractive/unattractive to you? Explain.
5. If you did not identify with your role, would you have preferred to play another role? Which one, and why?
6. Self-evaluate your own personal communication and collaboration skills during the simulation within your team, and with the public. A. What did you do well? and B. What did you not do so well?
7. Evaluate your team's ability to communicate and to collaborate during the simulation. A. What went well? And B. What did not go so well?
8. Based on your background knowledge and this simulation, do you think it is possible to forecast volcanic activity? Explain.

Part IV. Your Feedback:
Instructions: This section is to inform us of your positive and negative feedback about the simulation. Please be as honest and informative as possible.

1. Do you think that playing a specific role (with specific responsibilities) helped you to learn more about volcanoes, volcanic monitoring, and/or emergency management? Explain.
2. Do you think the simulation reflects volcanic monitoring and crisis management in real life? A. If so, what is the same? B. If not, what is different?
3. In your opinion, describe the pace of the simulation. (Example: too fast, too slow.. just right?)
4. How was the pace of the simulation relevant to… A. Your overall experience B. Your performance
5. Did you feel the simulation dragged on, or went by very quickly?
6. Describe the level of difficulty that you personally experienced. A. Did you find the parts of the simulation really hard? Too easy? Explain. B. What aspects were really challenging?

7. Describe your interactions with your instructors during the simulation. Did they help you and/or challenge you? Did they behave ‘in role’?
8. What parts of the simulation would you keep the same (in general and/or specific to your role)?
9. What parts of the simulation would you change (in general and/or specific to your role)?
10. Any other final comments or feedback?

D2.2. Participant Questionnaire (Iteration 3 & 4)

Question 1, 2, 3 – Communication perceptions and attitudes*
Question 4 – Demographics
Question 5 – Geology topics

Question 6 – Your Feedback
Instructions: The following questions are open-ended and are for us to understand how you experienced the simulation and the role that you played. Use your own words and please use examples to help you, if necessary. If you need more room, flip over the page and continue.

1. Did you feel sufficiently prepared for the simulation? Did the literature, lectures, and exercises help before the simulation? Which was most helpful? Why?
2. List the most important best practices (or good methods) of communication that scientists should use when talking with the public:
3. Self-evaluate your own personal communication skills during the simulation within your team, and with the public. A. What did you do well? B. What did you not do so well?
4. Evaluate your team’s ability to communicate during the simulation. A. What went well? B. What did not go so well?
5. What parts of the simulation would you keep the same (in general and/or specific to your role)?
6. What parts of the simulation would you change (in general and/or specific to your role)?
7. Any other final comments or feedback?

*Additional research will be carried out on the students’ communication perceptions

D3. Flow of Information Diagrams (Student Role Diagram)

The following two diagrams illustrate the ideal flow of information during the simulation. It also illustrates the specific student roles that are referred to in the results and discussion sections of Chapter 5. Refer to Figure D3.1 and Figure D3.2.

Figure D3.1. Flow of Information Map - GeoNet Team

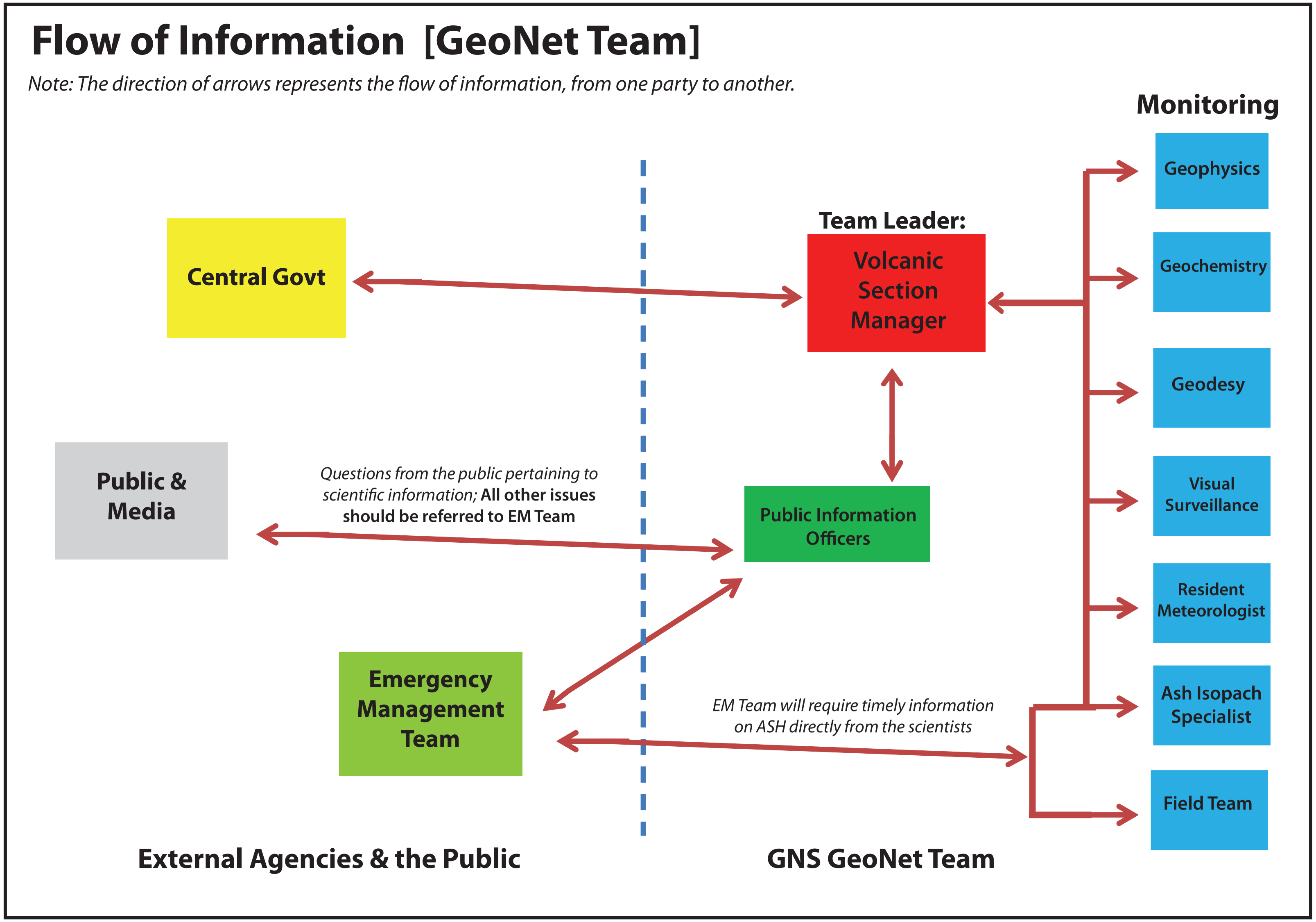
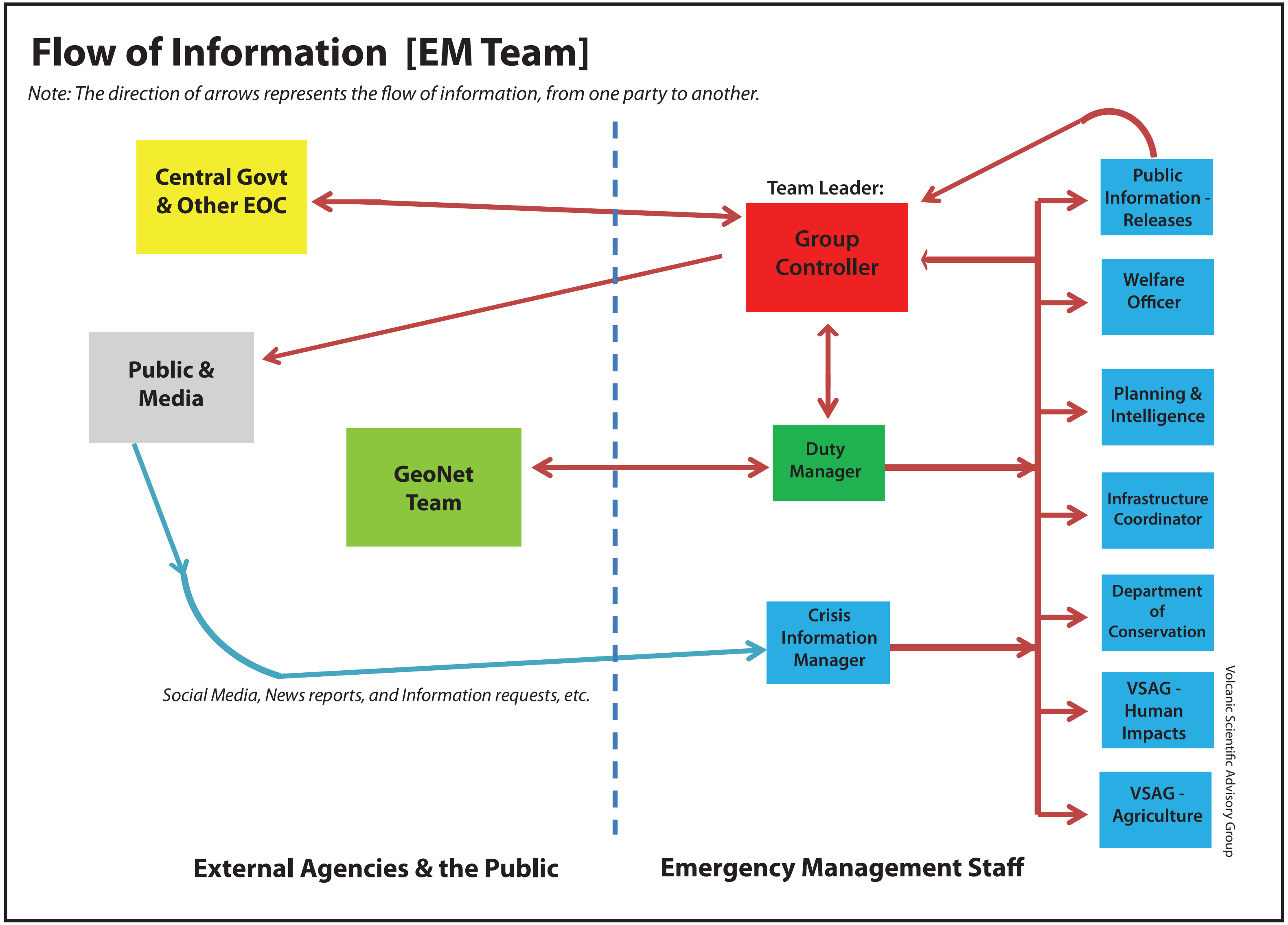
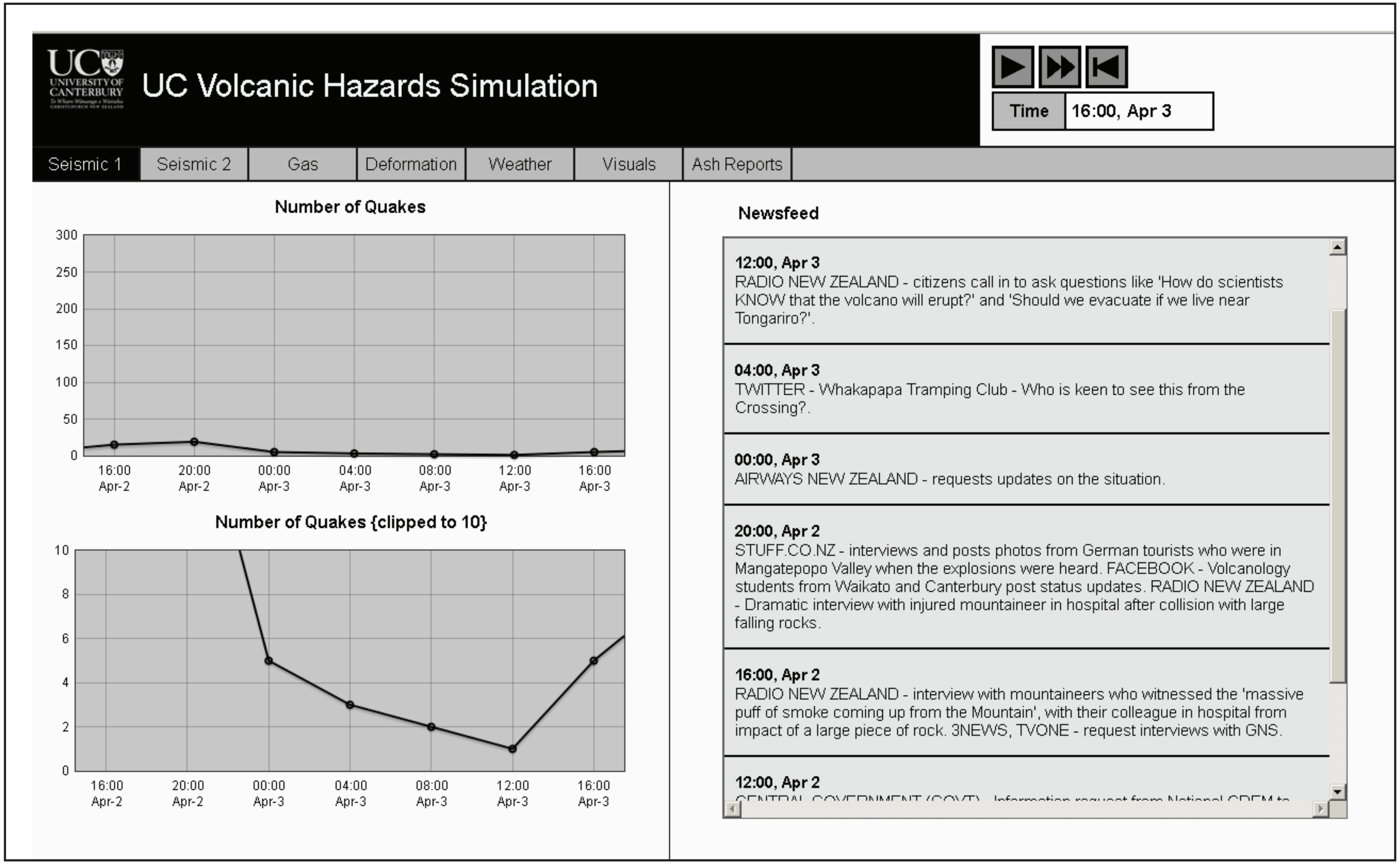


Figure D3.2 Flow of Information – Emergency Management Team



D4. Volcanic Hazards Website Interface



D5. Role Questionnaire

Questionnaire – Role Assignment
Instructions: This questionnaire is used to assign you to a role for the simulation. This is confidential and will not be shared with other class members or instructors. Fill in, or "bold" the responses, and return to the researcher.

Section 1 – Demographics ***(not included here)***

Section 2 - Statements
Instructions: Select if you "Agree", "Are neutral", or "Disagree" with the following statements about yourself.

1. People that know me would say that I am extroverted.
Agree Neutral Disagree

2. I am very comfortable presenting information in front of the class and my peers.
Agree Neutral Disagree

3. I have strong leadership skills.
Agree Neutral Disagree

4. I enjoy working under pressure.
Agree Neutral Disagree

5. I am very good at multi-tasking and task-prioritizing.
Agree Neutral Disagree

6. I am a team player, and I like working with other people.
Agree Neutral Disagree

7. I am very good at writing, and written communications.
Agree Neutral Disagree

8. I am a Maths-Quantitative person.
Agree Neutral Disagree

Section 3 Other Comments:
1. List your three favourite geology-related topics:
2. Are there any geology-related topics that you really dislike? List these.
3. List three other non-geology topics that really interests you.

D6. Student Library

Volcanic Hazards Simulation: Student Library

Topic: GeoNET + DOC Information	Papers:
Volcanic Eruption Meeting Agenda – Rules and To do lists for the GeoNET team meetings!	(Jolly & GeoNet, 2008)
Working on Volcanoes – Hazards and Risk Assessment	(GeoNet & GNS Science, 2009)
Tongariro Alpine Crossing Fact Sheet	(Department of Conservation, 2008)
Volcanic Alert Levels	(GeoNet, 2011a)
Aviation Alert Level Codes	(GeoNet, 2011b)
Topic: Volcanology + Monitoring	**Papers:**
Time-space modelling of activity from Tongariro	(Hobden, Houghton, Davidson, & Weaver, 1999)
Example of an Ash Isopach Map for recent eruptions from Ruapehu	(T. M. Wilson, 2010)
Explosive eruptions from Ngauruhoe; geology	(Nairn & Self, 1978)
Quantitative Real-time eruption forecasting, in Auckland	(Lindsay et al., 2009)
Volcanic and structural evolution of the TVZ	(C. J. N. Wilson et al., 1995)
Simple approaches to Volcanic Monitoring and Hazard Management	(Stoiber & Williams, 1990)
Seismic Precursors in the Auckland Volcanic Field	(Steven Sherburn, Scott, Olsen, & Miller, 2007)
Modelling geophysical precursors at Mt Tarawera	(S. Sherburn & Nairn, 2004)
Quantitative fall out models of ash; Used to determine ash cloud distributions (isopachs)	(Carey & Sparks, 1986); (Bebbington & Cronin, 2011)
Modelling ash distribution using RISKSCAPE	(Kaye, 2007)
VEI: Volcanic Explosivity Index	(Newhall & Self, 1982)
Basics on monitoring Gas, Seismic and Deformation	(Incorporated Research Institutions for Seismology; USGS, 2011)
Topic: Ash Impacts	**Paper**
Volcanic ash impacts on critical infrastructure	(Wilson, T. M. et al., 2011)
Volcanic ash leachates, a review	(Witham, Oppenheimer, & Horwell, 2005)
Aviation hazards from Volcanoes	(Prata & Tupper, 2009)
Recommendations for road managers and infrastructure during a volcanic eruption	(Auckland Engineering Lifelines Group Charter: Volcanic Impacts Study Group, 2009a)
Recommendations for electricity managers during a volcanic eruption	(Auckland Engineering Lifelines Group Charter: Volcanic Impacts Study Group, 2009b)
Recommendations for wastewater managers during a volcanic	(Auckland Engineering Lifelines Group Charter: Volcanic

eruption	Impacts Study Group, 2010)
Recommendations for water supply managers during a volcanic eruption	(Auckland Engineering Lifelines Group Charter: Volcanic Impacts Study Group, 2009c)
Aviation actions and regulations during a volcanic eruption	(Auckland Engineering Lifelines Group Charter: Volcanic Impacts Study Group, 2009d)
Impacts of ash, based on a Subplinian eruption from Tongariro	(Hitchcock & Cole, 2007)
Contamination of water supplies due to volcanic ash	(Stewart et al., 2006)
Impacts of ash on agriculture	(T. M. Wilson & Cole, 2007)
Topic: Media + Communication	**Paper**
Media Release to the Public after a small eruption on Ruapehu	(Ministry of Civil Defence & Emergency Management, 2007)
Media coverage after Ruapehu eruptions 1995, Reuters	(Reuters, 1995)
Example of news article after Ruapehu activity, and misquoting of scientist	(Smellie, 1995)
Alert Bulletin from Ruapehu, 2009	(Steven Sherburn & GeoNet, 2009)
Media Release to the Public after the Canterbury Earthquake	(Ministry of Civil Defence & Emergency Management, 2010a)

Topic: Hazard Planning, Organization and Communication	**Paper**
Organizational responses to a volcanic eruption	(Paton, Johnston, & Houghton, 1998)
Hazards, Hazard Maps and Geology of the Tungurahua Volcano	(Hall, 1999)
Map of the MCDEM Groups in New Zealand, and all the Regional Councils	(Ministry of Civil Defence & Emergency Management, 2002)
Advice to the Public during an eruption	(Ministry of Civil Defence & Emergency Management, 2010b)
Organization and need for CDEM Groups	(Ministry of Civil Defence & Emergency Management, 2009)
Risk Calculation and Probabilities of a volcanic event occurring, based on past events	(Newhall, Hoblitt, C., & R., 2002)

Topic: Social Impacts	**Paper**
Oral, mythical and social responses to volcanic eruptions; i.e. Mt. St. Helens	(Cashman & Cronin, 2008)
Short term and long term impacts of ash from Ruapehu (1995)	(Becker, Smith, Johnston, & Munro, 2001)

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APPENDIX E – CURRICULUM VITAE

Below is a selection of my curriculum vitae of conference attendance and contributions over the past three years:

E1. Publications:

Dohaney, J., Brogt, E., & Kennedy, B. (2012). Successful Curriculum Development and Evaluation of Group Work in an Introductory Mineralogy Laboratory. *Journal of Geoscience Education*.60, 21–33.

Dohaney, J., Kennedy, B., Brogt, E., and Bradshaw, H. (2012) The Geothermal World Videogame: An authentic, immersive videogame used to teach observation skills needed for Exploration. New Zealand Geothermal Workshop Proceedings, November 2012, Auckland New Zealand (Paper)

E2. Conference Proceedings:

Dohaney, Jacqueline, Brogt, E., Kennedy, Ben. (2012) Teaching Geology with 21st Century Techniques. GeoNZ 2012 Conference, Hamilton, New Zealand. Geoscience Society of New Zealand Miscellaneous Publications. (Talk)

Dohaney, J. A.; Kennedy, B.; Brogt, E.; Gravley, D.; Wilson, T.; O'Steen, B. (2011). American Geophysical Union, Fall Meeting 2011, San Francisco, California, U.S.A. Abstract #ED31A-0731 url link: http://adsabs.harvard.edu/abs/2011AGUFMED31A0731D (Poster)

Dohaney, Jacqueline (June, 2010) Volcanic Hazards Simulation: A Collaborative Role-Play Exercise using Multiple Synchronous Time Series Datasets to Perform Volcanic Forecasting and Hazard Management. Nanyang Geoscience Roundtable: Can Plinian Eruptions be Forecast? Philippines (Poster)

Dohaney, Jacqueline, Kennedy, Ben, Borella, M.W., Hamilton, C., and Gravley, Darren M. (2010) Volcanic Hazards Simulation: A Collaborative Role-Play Exercise using Multiple Synchronous Time Series Datasets to Perform Volcanic Forecasting and Hazard Management. Geological Society of America Abstracts with Programs, Denver, Colorado, USA. url link: http://gsa.confex.com/gsa/2010AM/finalprogram/abstract_181995.htm (Poster)

Dohaney, Jacqueline, Powell, Tom, Gravley, Darren M., Kennedy, Ben. (2010) The Geothermal Game: An Authentic, Problem-based Simulation Used to Teach Geothermal Energy Exploration and Exploitation Concepts. Geological Society of America Abstracts with Programs, Denver, Colorado, USA. url link: http://gsa.confex.com/gsa/2010AM/finalprogram/abstract_182059.htm (Talk)

Dohaney, Jacqueline, Powell, Tom, Gravley, Darren M., Kennedy, Ben. (2010) The Geothermal Game. GeoNZ 2010 Conference, Auckland New Zealand. Geoscience Society of New Zealand Miscellaneous Publication 129A: pg 83. (Talk)

Dohaney, J. and Kennedy, B. (2009) Successful Group Work in an Introductory Mineralogy Lab Setting. Portland GSA Annual Meeting (October, 2009) Paper No. 29-13, Geological Society of America Abstracts with Programs, Vol. 41, No. 7, p. 92. Portland, Oregon, USA (Poster)

E3. Teaching Experience:

2010 - Present **Lab, Field Teaching & Student Supervision,**
The University of Canterbury, Christchurch, New Zealand

From the beginning of my PhD, I have been a part of the demonstrating (tutoring) staff at Canterbury, and have been put in charge of the curricula and teaching of several courses:

- *GEOL242 – Rocks, Minerals and Ores,* (2010 – Present). This course is the core petrology course of the Canterbury undergraduate curricula. We teach the students how to use microscopes, mineral identification, rock classification, and rock petrogenesis. With previous teaching experience in mineralogy at other institutions, I re-developed the lab curricula in a literature-based way, and have been mentoring other graduate students on the 'best practices' of teaching mineralogy, and in a lab setting.
- *GEOL 240 – Field Studies: Mapping,* (2011 – Present). This is the first field course that students take at Canterbury, and is an introduction to field techniques and critical thinking in geology. I have co-taught on several field trips to Island Hills- Glens of Tekoa area.
- *GEOL 241 – Field Studies: Field Techniques*, (2011). This is the second field course students at Canterbury take, and the focus here is on improving field techniques, and structural geology. I have demonstrated on this trip in April, 2011.
- *GEOL 336 – Magmatic Systems and Volcanology*, (2011). This is a course specifically dedicated to igneous petrology concepts and microscopy. I demonstrated for the lab section of this course, as well as assisting in developing the curricula for the microscope portion of the class, and working with the lecturers on the structure of the class.
- *GEOL 337 - Exploration and Mining Geology* (2012- Present). In 2012 I was invited by the lecturer to create modern microscopy teaching techniques in the lab to introduce students to ore mineralogy and petrogenesis. The curricula development of this 'module' continues this year.
- *Frontiers Abroad*, *GEOL 476 –* Physical Volcanology, Geothermal Geology, (2010 to Present). The field portion of this course is run in the summer semester and is used to teach geology students advanced field techniques in Volcanology, and an introduction to

Geothermal geology. I have worked with the lecturers of this course to design training activities (part of my PhD research) to teach students transferable skills, critical thinking and decision making in these topics.
- 5 undergraduate and graduate students have carried out U.C. Summer Scholarships which I have supervised and helped learn basic geology research and transferable skills.

2007 - 2009 **Lab Demonstrator and Sessional Lecturer, The University of British Columbia, Vancouver, Canada**

During my Masters degree, I was trained and an integral part of the demonstrating (tutoring) staff at U.B.C. Upon completion of my degree, I was hired as a Sessional Lecturer to teach introductory topics.

- *EOSC 220 – Introductory Mineralogy,* (2007 – 2008). Introductory Mineralogy is a core course in the Geology and Geological Engineering U.B.C. undergraduate curricula. We teach the students mineral identification, mineral chemistry and mineral classification. I was initially a newly trained demonstrator in this course, and eventually, I re-developed and researched the lab curricula in a literature-based way with the assistance of a Teaching & Learning Fellow (Dr. Ben Kennedy).
- *EOSC 220 - Introductory Mineralogy* (2009). With the new lab curricula developed, I was hired to teach the first portion of this class' lecture. My co-staff (Dr. Mary Lou Bevier) designed the framework of the course, and we worked together to teach theoretical and applied concepts of Mineralogy.
- *EOSC 221 – Introductory Petrology* (2007 - 2009). This is a course specifically dedicated to igneous petrology concepts and microscopy. I demonstrated for the lab section of this course, and worked with the lecturer to organize and catalogue the rock and thin section collection.
- *EOSC 110, EOSC 114 – Introductory Geology, and Natural Hazards* (2009). I was hired in a Sessional Lecturing position to teach introductory geology and natural hazards topics during the summer semester at U.B.C. I taught these course alone, with mentoring provided by the Teaching Fellows (Brett Gilley, Carl Wieman Science Education Initiative)
- *MDRU (Mineral Deposits Research Unit) Short Course "ArcGIS for Geologists"*. (2009) MDRU Short Course Creator & Instructor